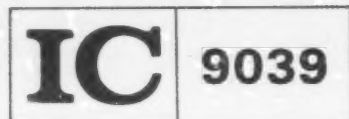


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Bureau of Mines Information Circular/1985

ORIGINAL

Chemically Enhanced Drilling

An Annotated Tabulation of Published Results

By Pamela J. Watson and William H. Engelmann



UNITED STATES DEPARTMENT OF THE INTERIOR



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Information Circular 9039

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UNITED STATES DEPARTMENT OF THE INTERIOR

Donald Paul Hodel, Secretary

BUREAU OF MINES

Robert C. Horton, Director

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

eq/L	equivalent per liter	mol	mole
g/L	gram per liter	mol/L	mole per liter
in	inch	<u>N</u>	normality
lb/ton	pound per ton	pct	percent
mg/g	milligram per gram	wt pct	weight percent
mg/L	milligram per liter		

CHEMICALLY ENHANCED DRILLING

An Annotated Tabulation of Published Results

By Pamela J. Watson¹ and William H. Engelmann²

ABSTRACT

This report presents a Bureau of Mines literature survey that provides a data base useful for current and future studies in the area of chemically enhanced drilling and cutting. Publications describing laboratory testing and field studies of drilling and cutting with chemical additives are reviewed. Significant results are summarized and tabulated by rock or material type and also by chemical additive, with extensive references. Selected studies related to fluid-enhanced processing or material testing are summarized in the appendixes.

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INTRODUCTION

The goals of the Bureau of Mines include that of increasing productivity in mining systems. Enhanced rates of fragmentation or excavation result from faster penetration rates of rock drills for blastholes, or other advanced drilling practices associated with the total mining process. Since large drilling machines are capital intensive and smaller rock drills are labor intensive, the enhancement of drilling rates has been a productivity goal for many decades as a response to these economic pressures. Flushing water had been used with many original designs of rock drills. However, it is not known when chemical additives were first used in these flushing fluids, since much of the early work in this area is known only through hearsay and was not published. Secondhand reports of this use of chemical additives began to appear in the literature, most notably in the 1920's.

In over 60 years of drilling technology, nearly 100 different additives have been reported in the literature, with many descriptions of their effects. However, results given for drillability on the same rock type, with the same additive, at the same concentration, vary widely from one researcher to another, depending upon experimental approach and conditions. Accordingly, the Bureau has undertaken this literature review in order to bring together all the results, albeit with their variances, and to present a concise, easily consulted data base as a guide for mining companies and drilling technologists, as well as a lead-in to chemically enhanced drilling and cutting research that is being pursued by the Bureau and others. Researchers in the United States and elsewhere

made progress in understanding the effects of chemical additives in the period 1960-75, but despite the importance of these studies, only limited advances have been made in the last decade. It is now generally accepted that there is no one generic mechanism that yields understanding of the accumulation of all phenomena or effects that are observed.

This review reports from the literature which chemicals have been found to enhance drilling and cutting of rocks and materials, summarizes these rock-fluid interactions, and tabulates the degrees and varieties of success for these interactions. In addition, many of the same rock-fluid combinations useful in enhancing drilling and cutting have also been used in studying (1) processing methods, such as comminution and grinding, flotation, or fragmentation, (2) surface effects, including adsorption, friction and wear, Rebinder effects, or zeta potential modifications to rock hardness, and (3) mechanical property alteration, including hardness, fracture and crack formation and propagation, and strength of materials. There are also numerous other rock-fluid combinations not yet reported in drilling practice that have been used in these related areas. Appendix A lists rock-fluid combinations used in processing studies, along with a corresponding bibliography; appendix B lists rock-fluid combinations used in surface effects studies, with bibliography; and appendix C lists rock-fluid combinations used in studies of the mechanical properties of materials, with bibliography. In addition, a general bibliography on drilling is listed in appendix D.

REVIEW OF LITERATURE

A great number of different rock types have been tested in both the field and the laboratory to determine the effects of various fluid additives on drilling performance. The following sections and tables summarize the reported relative success of the numerous chemical

additives and rock or material combinations in enhancing the drilling process.

ROCKS OR MATERIALS

Many different rocks or materials have been field- or laboratory-tested using a

great variety of fluid additives. The rocks and materials are--

Amygdaloidal basalt
 Anhydrite (including gypsum and sulfate rocks)
 Argillaceous rocks (including argillites, clays, schists, and shales)
 Calcium fluoride crystals
 Chert
 Coal (New South Wales coal measure and Novo Khazinskii and Arlanskii coal deposits of the Arlansk coal region)
 Diabase
 Diorite
 Dolomite
 Garnetite
 Granite (many varieties tested; see references for specific type)
 Granodiorite
 Greenstone
 Gritstone
 Hematite (including taconite)
 Igneous rocks (see also basalt, diabase, diorite, granite, granodiorite, and rhyolite and porphyry)
 Ironstone (including jaspilite)
 Limestone (including carbonate rock)
 Lithium fluoride crystals
 Magnesite
 Magnesium oxide crystals
 Marble
 Martite
 Microcline
 Pyrite
 Quartz
 Quartzite
 Rhyolite and porphyry
 Riebeckites
 Sandstone
 Serpentine
 Siderite
 Tuff

Table 1 summarizes the results of the drilling tests reported in the literature. This table breaks down the results first by rock type, then lists the chemical additives tested, the concentrations (footnoting the optimum concentration if available), the property of the rock or the drilling, the corresponding effect, and the specific reference. All effects were compared to those from drilling with water alone, unless otherwise noted.

CHEMICAL ADDITIVES

The literature has reported a great variety of chemical additives used in field or laboratory tests in attempts to enhance drilling in a given rock or material. These additives with their chemical formulas and/or general descriptions, if known, are--

Aerosol (no specific formula or description given)
 Aerosol C-61 (cationic surfactant)
 Aerosol OT (anionic surfactant)
 Aluminum chloride (AlCl_3)
 Ammonium nitrate (NH_4NO_3)
 Anionic detergent
 B.P.S.B.4 (soluble oil)
 Calcium chloride (CaCl_2)
 Calcium hydroxide [$\text{Ca}(\text{OH})_2$]
 Compound "M" (no specific formula or description given)
 Conco XAC (surfactant)
 Conco XAM (surfactant)
 Consoft C (surfactant)
 Consoft CP-50 (surfactant)
 Cutall oil (no specific formula or description given)
 Dimethylformamide (DMF) [$(\text{CH}_3)_2\text{NHC}=\text{O}$]
 Dimethylsulfoxide (DMSO) [$(\text{CH}_3)_2\text{SO}$]
 DMF in DMSO
 Disolvane 4411 (surfactant)
 Dodecylamino acetate ($\text{C}_{12}\text{H}_{25}\text{NH}_2\text{C}_3\text{H}_2\text{O}_2$)
 Dodecyltrimethyl ammonium bromide (DTAB) ($\text{C}_{15}\text{H}_{34}\text{NBr}$)
 Dromus B (soluble oil)
 Dromus B plus Esso 1 (combination of two soluble oils)
 Duomac T (surfactant)
 Ethyl alcohol ($\text{C}_2\text{H}_5\text{OH}$)
 Ethylene glycol ($\text{C}_2\text{H}_6\text{O}_2$)
 Ferric chloride (FeCl_3)
 Glycerine ($\text{C}_3\text{H}_8\text{O}_3$)
 Hetoxamine C-10 (surfactant)
 Hydrochloric acid (HCl)
 Intersoft 49 (surfactant)
 Kerosine
 Lime (CaO)
 Magnesium chloride (MgCl_2)
 Magnesium sulfate (MgSO_4)
 Marvansoft FBH (surfactant)
 Marvansoft FMA (surfactant)
 Mobil 1535 (soluble oil)

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
AMYGDALOIDAL BASALT ⁵				
Oleylammonium acetate.....	⁶ 0.01	Drilling costs.. Drilling rate...	Reduced..... Increased 20 to 50 pct.	4
Tergitol 7.....	⁶ .1	Drilling costs.. Drilling rate...	Reduced..... Increased 20 to 50 p.t.	
Tergitol NPX.....	⁶ .1	Drilling costs.. Drilling rate...	Reduced..... Increased 20 to 50 pct.	4
ANHYDRITE				
Aluminum chloride ⁷	0.1 - 1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 20 pct.....	18
Calcium chloride ⁷	.1 - 1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 20 pct.....	
Calcium hydroxide.....	⁶ 0.06	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased.....	18, 30
		Rock hardness... Rock strength...	Decreased..... Decreased 9 to 20 pct..	
Sodium carbonate ⁷	.1 - 1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 20 pct.....	18
Sodium chloride ⁷	.1 - 1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 20 pct.....	18
Sodium hydroxide.....	⁶ 0.05 - .1	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased.....	18, 30
		Rock hardness... Rock strength...	Decreased..... Decreased 9 to 20 pct..	
Do. ⁷	.1 - .2	Amount drilled.. Drilling rate... Drilling speed..	Increased..... ...do..... ...do.....	19
ARGILLACEOUS ROCKS				
SHALES				
Aluminum chloride.....	0.1	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased.....	30
		Rock hardness... Rock strength...	Decreased..... Decreased 9 to 20 pct..	
Do. ⁸⁻⁹	¹⁰ 0.0 - .05	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.	23
Do. ⁸⁻⁹	.0075- .03	Drill thrust.... Rock hardness...	Reduced..... ...do.....	24
Dromus B ¹¹	¹² .91 ¹³ .13	Bit life..... Drilling rate...	Increased very markedly ...do.....	9
Do. ¹¹	¹² .67 ¹⁴ .17	Bit wear..... Drilling rate...	Reduced..... Increased.....	10
		Drill vibration.. Lifting action.. Pump pressures..	Eliminated..... Improved..... Reduced.....	
Hydrochloric acid ⁸	.0 - .5	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.	23
Magnesium chloride ⁸	.0 - .5	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.	23
SMAD 1 ⁷	NA	NA.....	NE.....	5
Sodium carbonate.....	.25	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased.....	30
		Rock hardness... Rock strength...	Decreased..... Decreased 9 to 20 pct..	

See notes at end of table.

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
ARGILLACEOUS ROCKS--Continued				
SHALES--Continued				
Sodium carbonate ⁷	NA	Amount drilled.. Drilling rate... Drilling speed... Overall efficiency.	Slightly increased.... ...do..... ...do..... Increased.....	19
Do. ⁸	¹⁵ 0.0 - 0.5	Bit wear..... Drilling rate...	Decreased..... Increased 15 to 40 pct.	
Sodium carbonate, plus sodium hydroxide. ⁷	NA	Amount drilled.. Drilling rate... Drilling speed... Overall efficiency.	Slightly increased.... ...do..... ...do..... Increased.....	19
Sodium chloride ⁷	.25 1.0 - 2.0	Amount drilled.. Drilling rate... Drilling speed... Overall efficiency.	Slightly increased.... ...do..... ...do..... Increased.....	
Do. ⁸	¹⁶ 0.0 - 3.5	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.	23
Sulfanol ⁷	.05 - .15	Bit energy..... Bit friction... Drilling rate... Rock strength...	Decreased..... ...do..... Increased..... Decreased.....	
Sulfate soap ⁷	NA	N	NE.....	5
Thorium chloride ⁸	.0 - .03	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.	23
ARGILLITES AND SCHISTS				
Sodium carbonate.....	.1 - .25	Bit wear..... Drilling rate...	Decreased 10 to 35 pct. Increased 20 to 60 pct.	26
CLAY ROCKS				
Sodium chloride plus sodium carbonate.	.1 - .5	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30
SHALES, ARGILLITES AND SCHISTS, CLAY ROCKS				
Sodium chloride.....	.25 - .5	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30
CALCIUM FLUORIDE CRYSTALS ⁸				
Aluminum chloride.....	NA	NP.....	NE.....	31
Dimethyl formamide (DMF)...	0 -100	} Rock hardness...	Reduced.....	31-32
Dimethyl sulfoxide (DMSO)...	0 -100			
DMF in DMSO.....	0 - 50			
n-alkanes.....	NA	Drilling rate...	Increased.....	31
Toluene.....	NA	NP.....	NE.....	31
CHERT ¹¹				
Dromus B.....	¹⁷ 0.91 ¹⁸ .13	Bit life..... Drilling rate... Rod grease.....	Increased very markedly ...do..... Not required.....	9

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴	
CHERT ¹¹ --Continued					
Dromus B plus Esso 1.....	5 - 7	Bit life..... Drilling rate... Rod grease.....	Increased very markedly ...do..... Not required.....	9	
COAL					
Disolvane 4411 ¹⁹	NA	NP.....	NE.....		22
Dromus B ²⁰	1.0	Bit life..... Drilling rate... Rod grease.....	Increased markedly.... Increased..... Required.....	9	
OP-10 ¹⁹	0.05 - .12	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased.....		22
SNS ¹⁹	NA	NP.....	NE.....		
DIABASE ⁷					
Aluminum chloride.....	0.17 - 0.22	Drilling costs.. Drilling rate...	Decreased..... Significantly increased	19	
Magnesium chloride.....	.75 - 1.5	Drilling costs.. Drilling rate...	Decreased..... Slightly increased....		19
Magnesium sulfate.....	.25	Drilling costs.. Drilling rate...	Decreased..... Slightly increased....	19	
Sodium carbonate.....	.75	Drilling costs.. Drilling rate...	Decreased..... Slightly increased....		19
Sodium chloride.....	.4 - 1.0	Drilling costs.. Drilling rate...	Decreased..... Slightly increased....	19	
DIORITE ⁷					
Aluminum chloride.....	0.2	} Drilling rate... ...do.....	NE.....	19	
Sodium carbonate.....	.5				
Sodium chloride.....	.2		Increased.....	19	
DOLOMITE					
Dromus B ¹¹	0.13 - 0.91	Bit life..... Drilling rate... Rod grease.....	Increased markedly.... ...do..... Not required.....	9	
Do. ⁷	.67	Bit wear..... Drilling rate... Drill vibration. Lifting action.. Pump pressures..	Decreased..... Increased..... Eliminated..... Improved..... Reduced.....		10
Ethyl alcohol.....	NA	Drilling rate...	Increased 70 pct.....		
Hydrochloric acid.....	<1.0	Bit wear..... Drilling speed.. Rock hardness...	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....	18	
Sodium hydroxide plus sodium carbonate.	.06 - .2	Amount drilled.. Bit wear..... Drilling rate... Drilling speed..	Increased..... Decreased 54 pct..... Increased..... Slightly increased....		19
Sulfite cellulose lye.....	50	Bit wear..... Drilling speed.. Rock hardness...	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....		
Sulfonaphthenic petroleum acids.	1 - 2	Bit wear..... Drilling speed.. Rock hardness...	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....	18	
GARNETITE ²¹					
Solvac.....	1.0	Bit life..... Drilling rate... Rod grease.....	Increased markedly.... Increased very markedly Not required.....	9	

See notes at end of table.

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²		Property	Effect ³	References ⁴
GRANITE					
Aluminum chloride ⁸	0.05		Amount drilled..	Increased.....	19
			Drilling rate...	...do.....	
			Drilling speed..	...do.....	
Ammonium nitrate ⁷	.02		Amount drilled..	...do.....	19
			Bit corrosion...	Extreme.....	
			Drilling rate...	Increased.....	
			Drilling speed..	...do.....	
B.P.S.B.4 ²²	2.5		Bit life.....	Increased very markedly	9
Dromus B plus Esso 1 ¹¹	5	- 7	...do.....	...do.....	9
			Drilling rate...	...do.....	
Magnesium chloride ²³	.1		Amount drilled..	Increased.....	19
			Drilling rate...	...do.....	
			Drilling speed..	...do.....	
Mud: ⁸					
Bentonite clay.....	5.6		} Bit wear.....	Reduced.....	7
Sodium bicarbonate.....	.9				
Sodium chloride.....	13.4				
Tap water.....	80.05				
n-alcohols (methane to deconal).	NA		NP.....	NE.....	12, 32
Naphthenic acid soap plus sodium carbonate.	.25	- .5	Bit wear.....	Decreased 10 to 35 pct.	26
		.25	Drilling rate...	Increased 20 to 60 pct.	
Sodium carbonate ⁷	.25		Amount drilled..	Increased.....	19
			Drilling rate...	...do.....	
			Drilling speed..	...do.....	
Sodium chloride ⁷	.1	- .5	Amount drilled..	...do.....	19
			Drilling rate...	...do.....	
			Drilling speed..	...do.....	
Aerosol C-61 ⁸ mol/L..	10 ⁻⁴	- 10 ⁻²	Bit life.....	Increased 4 to 5 times.	12, 14, 16, 18
			Bit wear.....	Decreased 4.8 times....	
			Drilling rate...	Increased.....	
Aerosol OT ⁸ mol/L..	10 ⁻³	- 10 ⁻²	NP.....	NE.....	14
Aluminum chloride ⁸ ..mol/L..	3 × 10 ⁻⁶		Bit wear.....	Minimized.....	1, 14
			Rock hardness...	Maximized.....	
Dodecyltrimethyl ammonium bromide (DTAB) ⁸ mol/L..	10 ⁻⁴	- 10 ⁻³	Bit life.....	Increased.....	8, 12, 14-15, 17, 32
			Drilling costs..	Reduced.....	
			Drilling rate...	Increased 3 to 4 times.	
GRANODIORITE					
Aluminum chloride.....	0.01	- 0.05	Drilling rate...	Increased.....	6
			Rock hardness...	Minimized.....	
Magnesium chloride.....	.01	- .05	Drilling rate...	Increased.....	6
			Rock hardness...	Minimized.....	
Do. ^{7,23}	.9	- 1.5	Drilling rate...	Increased.....	19
Sodium carbonate.....	.01	- .1	...do.....	...do.....	6
			Rock hardness...	Minimized.....	
Sodium chloride ^{7,23}		1.0	Drilling rate...	Increased.....	19
Do.....		.1	...do.....	...do.....	6
			Rock hardness...	Minimized.....	
Sugar.....	.1	- 1.0	Drilling rate...	Increased.....	6
			Rock hardness...	Minimized.....	
Aluminum chloride.....N..		.005	} ...do.....	...do.....	3
Magnesium chloride.....N..		.05			
Sodium chloride.....N..		.05			

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
GREENSTONE				
Aerosol ¹⁴	0.8	Drilling effectiveness.	Increased.....	11
Compound "M" ²⁴	.2			
Cutall oil ²⁴	20.0			
Kerosine ²⁴	Pure			
Mobil 1535 ²¹	4.0	Bit life.....	NE.....	9
		Drilling rate...		
Water ²⁴⁻²⁵	Nap	Drilling effectiveness.	Increased to maximum...	11
GRITSTONE				
Aluminum chloride ⁷⁻⁸	0.0 - 0.05	Bit wear.....	Reduced.....	23
		Drilling rate...	Increased 15 to 40 pct.	
Do. ⁷⁻⁸	.0075- .03	Drill thrust....	Reduced.....	24
		Rock hardness...	...do.....	
Hydrochloric acid ⁸⁻⁹	.0 - .5	NP.....	NE.....	23
Magnesium chloride ⁸⁻⁹	.0 - .3			
Sodium carbonate ⁸⁻⁹	.0 - .5			
Sodium chloride ⁸⁻⁹	.0 - 3.5			
Thorium chloride ⁸⁻⁹	.0 - .03			
HEMATITE				
Aluminum chloride.....	0.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Ferric chloride.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Sodium chloride.....	0.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Aerosol C-61 ^{8,26} mol/L..	10 ⁻⁴ - 10 ⁻²	Bit life.....	Increased 5-fold.....	13
		Bit wear.....	Decreased 4.8 times....	
IGNEOUS ROCKS ²⁷				
Aluminum chloride.....	0.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate...	Increased.....	
		Rock hardness...	Decreased.....	
		Rock strength...	Decreased 9 to 20 pct..	30
Sodium carbonate plus soap (unspecified).	.25	Bit life.....	Increased.....	
	.25	Bit wear.....	Decreased.....	
		Drilling rate...	Increased.....	
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	
Sodium chloride.....	0.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate...	Increased.....	
		Rock hardness...	Decreased.....	
		Rock strength...	Decreased 9 to 20 pct..	

See notes at end of table.

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴	
IRONSTONE					
Aluminum chloride ⁷	0.1 - 0.15	Amount drilled.. Bit wear..... Drilling rate... Drilling speed..	Increased..... Decreased 26 pct..... Increased..... ...do.....	19	
Dromus B ¹¹	28.91 29.13	Bit life..... Bit wear..... Drilling rate... Drill vibration.. Lifting action.. Pump pressures..	Increased very markedly Decreased..... Increased very markedly Eliminated..... Improved..... Reduced.....		9 9-10 9-10 9-10 9-10 9-10
Do. ³⁰⁻³¹	NA	Bit life..... Drilling rate... Rod grease.....	Increased very markedly Increased markedly.... Not required.....		9
Magnesium chloride ⁷	.3	Amount drilled.. Bit wear..... Drilling rate... Drilling speed..	Increased..... Decreased 26 pct..... Increased..... ...do.....		
Sodium chloride ⁷	.25	Amount drilled.. Bit wear..... Drilling rate... Drilling speed..	...do..... Decreased 26 pct..... Increased..... ...do.....	19	
LIMESTONE					
Aluminum chloride ⁸⁻⁹	0.0 - 0.5	Bit wear..... Drilling rate...	Reduced..... Increased 9 pct.....	23	
Calcium chloride.....	1.0	Amount drilled.. Drilling rate... Drilling speed..	Increased..... ...do..... ...do.....		19
Calcium hydroxide.....	.05 - .07	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	...do..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30	
Hydrochloric acid ^{7,32}	1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 10 to 70 pct.		18
Do. ³²	.1 - .3	Amount drilled.. Drilling rate... Drilling speed..	Increased..... ...do..... ...do.....	19	
Do. ^{8-9,32}	.0 - .5	Bit wear..... Drilling rate...	Reduced..... Increased 9 pct.....		23
Magnesium chloride.....	15.25 - 1.0	Amount drilled.. Drilling rate... Drilling speed..	Increased..... ...do..... ...do.....	19	
Do. ⁸⁻⁹	.0 - .3	Bit wear..... Drilling rate...	Reduced..... Increased 9 pct.....		23
Magnesium sulfate.....	.75 - 1.0	Amount drilled.. Drilling rate... Drilling speed..	Increased..... ...do..... ...do.....	19	
Mud: ⁸					
Bentonite clay.....	5.6	} Bit wear.....	Reduced.....	7	
Sodium bicarbonate.....	.95				
Sodium chloride.....	13.4				
Tap water.....	80.05				
Oil soap.....	.1 - 1.0	Amount drilled.. Drilling rate... Drilling speed..	Increased..... ...do..... ...do.....	19	

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
LIMESTONE--Continued				
Sodium carbonate ⁷	0.25	Amount drilled..	Increased.....	19
		Bit life.....	...do.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	19, 26, 30
		Drilling speed..	Increased.....	19
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Do. ⁷	0.1 - 1.0	Bit wear.....	Decreased 10 pct.....	} 18
		Drilling speed..	Decreased 10 to 20 pct.	
Do.....	.0 - .5	Amount drilled..	Increased.....	} 19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Do. ⁸⁻⁹	.0 - .5	Bit wear.....	Reduced.....	} 23
		Drilling rate...	Increased 9 pct.....	
Sodium chloride ⁷	.25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Do.....	.75	Amount drilled..	Increased.....	} 19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Do. ⁸⁻⁹	16.0 - 3.5	Bit wear.....	Reduced.....	} 23
		Drilling rate...	Increased 9 pct.....	
Sodium hydroxide.....	.05	Bit life.....	Increased.....	} 30
		Bit wear.....	Decreased.....	
		Drilling rate...	Increased.....	
		Rock hardness...	Decreased.....	
		Rock strength...	Decreased 9 to 20 pct..	
Do.....	.1 - .2	Amount drilled..	Increased.....	} 19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Sodium hydroxide plus sodium carbonate (1:1).	.05 - .2	Amount drilled..	...do.....	} 19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Sodium phosphate ⁷	.1	Bit wear.....	Decreased 10 to 35 pct.	} 26
		Drilling rate...	Increased 20 to 60 pct.	
Sodium silicate ⁷	.025	Bit wear.....	Decreased 10 to 35 pct.	} 26
		Drilling rate...	Increased 20 to 60 pct.	
Sulfite cellulose lye ⁷	50	Bit wear.....	Decreased 10 pct.....	} 18
		Drilling speed..	Increased 10 to 70 pct.	
		Rock hardness...	Decreased 30 to 50 pct.	
Sulfonaphthenic petroleum acids. ⁷	1 - 2	Bit wear.....	Decreased 10 pct.....	} 18
		Drilling speed..	Increased 10 to 70 pct.	
		Rock hardness...	Decreased 30 to 50 pct.	
Thorium chloride ⁸⁻⁹	.0 - .03	Bit wear.....	Reduced.....	} 23
		Drilling rate...	Increased 9 pct.....	
LITHIUM FLUORIDE CRYSTALS ⁸⁻⁹				
DMF.....	NA NA NAP	Bit life.....	Increased.....	13
Toluene.....				
Water ²⁵				
See notes at end of table.				

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²		Property	Effect ³	References ⁴
MAGNESITE					
Aluminum chloride.....	0.1		Bit life.....	Increased.....	30
			Bit wear.....	Decreased 10 to 35 pct.	26, 30
			Drilling rate...	Increased 20 to 60 pct.	26, 30
			Rock hardness...	Decreased.....	30
			Rock strength...	Decreased 9 to 20 pct..	30
Ferric chloride.....	.1		Bit life.....	Increased.....	30
			Bit wear.....	Decreased 10 to 35 pct.	26, 30
			Drilling rate...	Increased 20 to 60 pct.	26, 30
			Rock hardness...	Decreased.....	30
			Rock strength...	Decreased 9 to 20 pct..	30
Sodium chloride.....	0.1	- .25	Bit life.....	Increased.....	30
			Bit wear.....	Decreased 10 to 35 pct.	26, 30
			Drilling rate...	Increased 20 to 60 pct.	26, 30
			Rock hardness...	Decreased.....	30
			Rock strength...	Decreased 9 to 20 pct..	30
MAGNESIUM OXIDE CRYSTALS ⁸					
Aluminum chloride.....		NA	Drilling rate...	Increased.....	32
DMF.....	0	-100	...do.....	...do.....	15, 32
DMSO.....	0	-100	...do.....	...do.....	32
DMF in DMSO.....	0	- 50	...do.....	Increased 20 times.....	8, 32
			Rock hardness...	Decreased.....	31
n-alkanes ³³		NA	Drilling rate...	Increased 8 times.....	20, 32
Toluene.....		Pure	...do.....	Increased.....	15, 32
Water.....		NAP	...do.....	NE.....	15
Sodium chloride.....N..		10 ⁻²	Bit life.....	Increased 5 times.....	13
			Drilling rate...	Increased.....	8
MARBLE ⁸					
Aluminum chloride.....	0.5	- 1.0	Drilling rate...	NE.....	2
Magnesium chloride.....		NA	...do.....	NE.....	29
Mud:					
Bentonite clay.....		5.6	} Bit wear.....	Reduced.....	7
Sodium bicarbonate.....		.95			
Sodium chloride.....		13.4			
Tap water.....		80.05			
Soap.....	.25	- .5	} Drilling rate...	NE.....	2
Sodium carbonate.....	.2	- 1.0			
Sodium hydroxide.....	.025	- .25			
Quat 316.....mol/L..	10 ⁻³	- 10 ⁻²			
MARTITE					
Aluminum chloride.....	0.1		Bit life.....	Increased.....	30
			Bit wear.....	Decreased 10 to 35 pct.	26, 30
			Drilling rate...	Increased 20 to 60 pct.	26, 30
			Rock hardness...	Decreased.....	30
			Rock strength...	Decreased 9 to 20 pct..	30
Ferric chloride.....	.1		Bit life.....	Increased.....	30
			Bit wear.....	Decreased 10 to 35 pct.	26, 30
			Drilling rate...	Increased 20 to 60 pct.	26, 30
			Rock hardness...	Decreased.....	30
			Rock strength...	Decreased 9 to 20 pct..	30
Sodium chloride.....	0.1	- .25	Bit life.....	Increased.....	30
			Bit wear.....	Decreased 10 to 35 pct.	26, 30
			Drilling rate...	Increased 20 to 60 pct.	26, 30
			Rock hardness...	Decreased.....	30
			Rock strength...	Decreased 9 to 20 pct..	30

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
MICROCLINE				
Aluminum chloride ⁸	0.0001- 1.0	} NP.....	NE.....	29
Magnesium chloride ⁸	.0001- 1.0			
DTAB.....mol/L..	10 ⁻⁴ - 10 ⁻³	Drilling rate...	Increased.....	15, 29
PYRITE				
Aluminum chloride.....	0.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Ferric chloride.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Sodium chloride.....	0.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Do. ⁷⁻⁸	.1 - .5	Drilling speed..	Increased.....	19
QUARTZ				
Aluminum chloride ⁷	0.01 - 0.05	Drilling rate...	Increased.....	} 6
		Rock hardness...	Decreased.....	
Do.....	.02 - .1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Do. ⁷	.7 - 1.0	Amount drilled..	Increased.....	} 19
		Bit wear.....	Decreased 34 pct.....	
		Drilling speed..	Increased.....	
B.P.S.B.4 ²²	2.5	Bit life.....	Increased very markedly	9
Dodecylamino acetate ⁷	NA	Bit wear.....	Decreased 2 to 3 times.	25
Dromus B plus Esso 1 ¹¹	5 - 7	Bit life.....	Increased very markedly	} 9
		Drilling rate...	...do.....	
		Rod grease.....	Not required.....	
Kerosine ⁷	Pure	Bit friction....	Decreased 7 times.....	} 25
		Bit wear.....	Decreased 40 times.....	
Magnesium chloride ⁷	.01 - .05	Drilling rate...	Increased.....	} 6
		Rock hardness...	Decreased.....	
Do. ⁷	.1 - .5	Bit wear.....	Decreased 10 to 35 pct.	} 26
		Drilling rate...	Increased 20 to 60 pct.	
n-alcohols ⁸	NA	...do.....	Increased 20-fold.....	8
		...do.....	NE.....	29
Naphthenic acid soap ⁷	NA	Bit wear.....	Decreased 10 to 35 pct.	} 26
		Drilling rate...	Increased 20 to 60 pct.	
Naphthenic oil.....	.25 - .5	Bit life.....	Increased.....	} 30
		Bit wear.....	Decreased.....	
		Drilling rate...	Increased.....	
		Rock hardness...	Decreased.....	
		Rock strength...	Decreased 9 to 20 pct..	

See notes at end of table.

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
QUARTZ--Continued				
Naphthenic oil plus sodium carbonate.	0.25 .25	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30
Oleylammonium acetate ⁸	.7	Drilling rate...	Increased 50 pct.....	
Petroleum sulfonate ⁷	0.25 - .5	Bit wear..... Drilling rate...	Decreased 10 to 35 pct. Increased 20 to 60 pct.	
Potassium chloride ⁷	.01 - .5	Bit wear..... Drilling rate...	Decreased 10 to 35 pct. Increased 20 to 60 pct.	
Sodium carbonate ⁷	.01 - .1	...do..... Rock hardness...	Increased..... Decreased.....	
Sodium chloride ⁷	.1 - .5	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30
Do. ⁷	.1	Drilling rate... Rock hardness...	Increased..... Decreased.....	6
Sodium hydroxide ⁷	.1 - 1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 20 pct.....	
Sodium oleate ⁷	NA	Bit wear.....	Decreased 2 to 3 times.	25
Sodium orthophosphate ⁷	1.0 - 2.0	...do..... Drilling speed.. Rock hardness...	Decreased 10 pct..... Increased 20 pct..... Decreased 60 to 70 pct.	18
Sodium pyrophosphate ⁷	1.0 - 2.0	Bit wear..... Drilling speed.. Rock hardness...	Decreased 10 pct..... Increased 20 pct..... Decreased 60 to 70 pct.	
Sugar ⁷	.1 - 1.0	Drilling rate... Rock hardness...	Increased..... Decreased.....	
Toluene ⁸	Pure NAP	Drilling rate...	Increased 20-fold.....	8
Water ^{8,25}				
DTAB ⁸ mol/L..	10 ⁻⁴ - 10 ⁻³	Bit life..... Drilling costs.. Drilling rate...	Increased 4-fold..... Reduced..... Increased 20-fold.....	15 15 8
QUARTZITE				
Aluminum chloride ^{7,23}	0.1 - 0.15	Amount drilled.. Bit wear..... Drilling rate... Drilling speed..	Increased..... Decreased 26 pct..... Increased..... ...do.....	19
Anionic detergent ⁸	4, 8, 12	Bit energy..... Bit friction.... Bit life..... Bit wear..... Drilling costs.. Drilling rate... Overall efficiency.	...do..... ...do..... ...do..... Decreased..... Decreased 30 pct..... Increased..... Increased 60 pct.....	
Dromus B ¹¹	34.91 35.13	Bit life..... Bit wear..... Drilling rate... Drill vibration.. Lifting action.. Pump pressures..	Increased very markedly Decreased..... Increased very markedly Eliminated..... Improved..... Reduced.....	9 9-10 9-10 10 10 10

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
QUARTZITE--Continued				
Ethylene glycol ⁸	4, 8, 12	Bit energy.....	Increased.....	28
		Bit friction....	...do.....	28
		Bit life.....	...do.....	21, 27
		Bit wear.....	Decreased.....	28
		Drilling costs..	Decreased 30 pct.....	27
		Drilling rate...	Increased.....	21, 28
Ferric chloride ^{7,23}	.48	Amount drilled..	Increased.....	19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate...	Increased.....	
		Drilling speed..	...do.....	
Glycerine ⁸	4, 8, 12	Bit energy.....	...do.....	28
		Bit friction....	...do.....	28
		Bit life.....	...do.....	21, 27
		Bit wear.....	Decreased.....	28
		Drilling costs..	Decreased 30 pct.....	27
		Drilling rate...	Increased.....	21, 28
Magnesium chloride ^{7,23}	.3	Amount drilled..	...do.....	19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate...	Increased.....	
		Drilling speed..	...do.....	
Mobil 1535 ²¹	4.0	Bit life.....	NE.....	9
		Drilling rate...		
Sodium chloride ^{7,23}	.25	Amount drilled..	Increased.....	19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate...	Increased.....	
		Drilling speed..	...do.....	
Solvac ²¹	1.0	Bit life.....	Increased very markedly	9
		Drilling rate...	...do.....	
Water ^{3,25}	NAP	NP.....	NE.....	21
Aerosol C-61 ⁸ mol/L..	10 ⁻³	Bit life.....	Increased 4 times.....	13-14
		Bit wear.....	Decreased 4.8 times....	
		Drilling rate...	Increased.....	
RHYOLITE AND PORPHYRY				
RHYOLITE ²²				
B.P.S.B. ⁴	2.5	Bit life.....	Increased very markedly	9
RHYOLITE PORPHYRY ⁸				
Conco-XAC.....	.032	NP.....	NE.....	15
Conco-XAM.....	>1.0			
Consoft C.....	<.001			
Consoft CP-50.....	.0016			
Duomac T.....	<.001			
Hetoxamine C-10.....	.0016			
Intersoft 49.....	.001			
Marvansoft FBH.....	.25	Bit life.....	Increased 5-fold.....	15
		Drilling costs..	Decreased 50 pct.....	
Marvansoft FMA.....	.025	NP.....	NE.....	15
Solar CL-385.....	<.001			
Torque trim.....	2.0			
Aerosol C-61 ³⁶ mol/L..	10 ⁻⁴ - 10 ⁻³	Bit life.....	Increased.....	13
		Bit wear.....	Decreased.....	
PORPHYRY				
Mobil 1535 ²¹	4.0	NP.....	NE.....	9
Sodium chloride ⁷	.1 - .25	Amount drilled..	Increased.....	19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
		Dust.....	Decreased.....	

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²		Property	Effect ³	References ⁴	
RIEBECKITES ⁷						
Dromus B.....	0.91		Bit wear..... Drilling rate... Drill vibration. Lifting action.. Pump pressures..	Decreased..... Increased..... Eliminated..... Improved..... Reduced.....	9	
SANDSTONE						
Aluminum chloride.....	0.3		Bit wear..... Drilling rate... Dust.....	Decreased 28 to 42 pct ⁸ Increased ⁷ Decreased ⁷	19	
Do. ⁸	0.0	.5	Bit wear..... Drilling rate...	...do..... Increased 15 to 40 pct.		23
Do. ⁸	.0075-	.03	Drill thrust.... Rock hardness...	Reduced..... Decreased.....		
B.P.S.B. ⁴²²	2.5		Bit life.....	Increased very markedly	9	
Calcium hydroxide.....	.05	.07	...do..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30	
Hydrochloric acid ⁸	.0	.5	Bit wear..... Drilling rate...	Decreased..... Increased 15 to 40 pct.		23
Lime.....	.05	.07	Bit wear..... Drilling rate...	Decreased 10 to 35 pct. Increased 20 to 60 pct.		
Magnesium chloride ⁸	.0	.3	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased 15 to 40 pct.		19 19 23
Mud: ⁸						
Bentonite clay.....	5.6	}	Bit wear.....	Reduced.....	7	
Sodium bicarbonate.....	.95					
Sodium chloride.....	13.4					
Tap water.....	80.05					
Oil soap ⁷	.1	Drilling rate... Dust.....	Increased..... Decreased.....	19		
SMAD 1 ⁷	NA	Bit friction... Rock strength... Torsional moment	...do..... ...do..... ...do.....		5	
Sodium carbonate.....	.25	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30		
Do.....	.3	.5	Bit wear..... Drilling costs.. Drilling speed.. Dust.....		Decreased 2.5 times.... Slightly reduced..... Increased 4 times..... Decreased.....	19
Do. ⁸	.0	.5	Bit wear..... Drilling rate...		Reduced..... Increased 15 to 40 pct.	
Sodium chloride.....	.25	Amount drilled ⁸ . Bit life..... Bit wear..... Drilling rate... Drilling speed ⁸ . Rock hardness... Rock strength...	Increased..... ...do..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Increased..... Decreased..... Decreased 9 to 20 pct..		19, 26, 30 26, 30 19 30 30	
Do. ⁸	.0	3.5	Bit wear..... Drilling rate...			Decreased..... Increased 15 to 40 pct.

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴		
SANDSTONE--Continued						
Sodium chloride plus sodium carbonate.	0.25 .25	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30		
Sulfanol ⁷	0.05 - .15	Bit energy..... Bit friction.... Drilling rate... Rock strength...	Decreased..... ...do..... Increased..... Decreased.....	5		
Sulfate soap ⁷	NA	Bit friction.... Rock strength... Torsional moment	...do..... ...do..... ...do.....		5	
Thorium chloride ⁸	.0 - .03	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.			23
SERPENTINE ⁶						
Aluminum chloride.....	0.0001- 1.0	NP.....	NE.....	2		
SIDERITE ⁷						
Calcium hydroxide.....	0.05 - 0.07	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30		
Sodium carbonate.....	.25	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30		
TUFF ²²						
B.P.S.B.4.....	2.5	Bit life.....	Increased very markedly	9		

NA Not available. NAp Not applicable.

NE No added effect reported. NP No specific property reported.

¹Reference to specific products does not imply endorsement by the Bureau of Mines.²Concentrations are given in weight percent unless otherwise indicated.³Compared to drilling with water alone.⁴Numbers refer to items in the list of references preceding the appendixes.⁵Field test using AXL (1.185-in-ID) bit. ⁶Optimum reported concentration.⁷Field test(s), no bit size given. ⁸Laboratory test(s).⁹Compared to dry drilling, not to water.¹⁰Optimum reported concentration was 0.01 pct.¹¹Field test using NX (3.0-in-ID) bit. ¹²Hard shales.¹³Soft shales. ¹⁴Very soft shales.¹⁵Optimum reported concentration was 0.25 pct.¹⁶Optimum reported concentration was 0.1 pct.¹⁷Hard chert. ¹⁸Soft chert.¹⁹Novo Khazinskii and Arlanskii coal deposits, Arlansk region, field tests.²⁰New South Wales coal measure, field tests. ²¹Field test using AX (1.91-in-ID) bit.²²Field test using BX (2.375-in-ID) bit and NX (3.0-in-ID) bit.²³Industrial tests. ²⁴Field test using EX (1.5-in-ID) bit.²⁵Water used as drilling fluid, not just for comparison purposes.²⁶Tests on hematite and taconite. ²⁷Recommended for all low-silica, igneous rocks.²⁸Hard ironstone. ²⁹Soft ironstone.³⁰Field tests using AX (1.91-in-ID) bit and BX (2.375-in-ID) bit. ³¹Jaspilite.³²Reported that the reactant fluid, calcium chloride, produced the enhanced results.³³Using hexadecane produced the enhanced results.³⁴Hard quartzite. ³⁵Soft quartzite.³⁶Using BX (2.375-in-ID) bit.

Mud

(formula, in percent:

Bentonite clay.....	5.6
Sodium bicarbonate.....	.95
Sodium chloride.....	13.4
Tap water.....	80.05)
n-alcohols ($C_nH_{2n+1}OH$)	
n-alkanes (C_nH_{2n+2})	
Naphthenic acid soap	
Naphthenic acid soap plus sodium carbonate	
Naphthenic oil	
Naphthenic oil plus sodium carbonate	
Oil soap	
Oleylammonium acetate ($C_{18}H_{35}NH_3C_2H_3O_2$)	
OP-10 (nonionic surfactant)	
Petroleum sulfonate	
Potassium chloride (KCl)	
Quat 316 (dodecylethyldimethyl ammonium bromide) ($C_{17}H_{36}NH_3Br$)	
SMAD (surfactant)	
SNS (surfactant)	
Soap (unspecified)	
Sodium carbonate (Na_2CO_3)	
Sodium carbonate plus soap	
Sodium chloride (NaCl)	
Sodium chloride plus sodium carbonate	
Sodium hydroxide (NaOH)	

Sodium hydroxide plus sodium carbonate

Sodium oleate ($NaC_{18}H_{33}O_2$)Sodium orthophosphate (Na_5PO_4)Sodium phosphate (Na_3PO_4)Sodium pyrophosphate ($Na_4P_2O_7$)Sodium silicate (Na_2SiO_3)

Solar CL-385 (surfactant)

Solvac (soluble oil)

Sugar ($C_{12}H_{22}O_{11}$)

Sulfanol (surfactant)

Sulfate soap (surfactant)

Sulfite cellulose lye (byproduct of paper manufacturing)

Sulfonaphthenic petroleum acids (byproduct of paper manufacturing)

Tergitol 7 (sodium heptadecyl surfactant) ($NaC_{16}H_{33}SO_4$)

Tergitol NPX (36-carbon nonionic surfactant, nonylphenol-polyethylene oxide)

Thorium chloride ($ThCl_4$)Toluene (C_7H_8)

Torque trim (surfactant)

Water (H_2O)

Table 2 summarizes the results of the drilling tests in the same manner as table 1, but by order of chemical additive rather than rock type.

DISCUSSION

This literature survey was pursued to catalog the diversity of chemical additives and to report on the wide variations that have been found in their ability to increase efficiency in drilling. Many different chemical-rock combinations were tested, many at several chemical concentration levels. The research results reported in the literature dealt with the effect of chemical additives on rocks in such areas as rock hardness, bit wear, electrochemical effects, and drilling penetration rates. These results were used as a starting point for laboratory testing now going on in the Bureau to determine the basic

reason why some fluids worked for some chemical-rock combination at a given concentration in some, but not all, areas of application.

Experimental laboratory drilling tests are being performed with several chemical-rock combinations, in conjunction with studies of rock hardness changes, surface modification effects, bit wear rates, and penetration rates. These laboratory studies are being done to gain a better understanding of enhanced drilling and to give drilling technologists some guidelines for choosing the best chemical additive for a given drilling task.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
AEROSOLS				
Greenstone.....	0.8	Drilling effectiveness.	Increased.....	11
AEROSOL C-61 ⁴				
Granite.....	5×10^{-4} - 10^{-2}	Bit life.....	Increased 4 to 5 times.	12, 14, 16, 18
		Bit wear.....	Decreased 4.8 times....	
		Drilling rate..	Increased.....	
Hematite ⁶	5×10^{-4} - 10^{-2}	Bit life.....	Increased 5-fold.....	13
		Bit wear.....	Decreased 4.8 times....	
Quartzite.....	5×10^{-3}	Bit life.....	Increased 4 times.....	13-14
		Bit wear.....	Decreased 4.8 times....	
		Drilling rate..	Increased.....	
Rhyolite porphyry ⁷	5×10^{-4} - 10^{-3}	Bit life.....	...do.....	13
		Bit wear.....	Decreased.....	
AEROSOL OT ⁴				
Granite.....	5×10^{-3} - 10^{-2}	NP.....	NE.....	14
ALUMINUM CHLORIDE				
Anhydrite ⁸	0.01 - 1.0	Bit wear.....	Decreased 10 pct.....	18
		Drilling speed.	Increased 20 pct.....	
Argillaceous rocks (shales).....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Reduced.....	
		Rock strength..	Decreased 9 to 20 pct..	
Do. ^{4,9}	10^{-6} - .05	Bit wear.....	Reduced.....	23
		Drilling rate..	Increased 15 to 40 pct.	
Do. ^{4,9}	.0075- .03	Drill thrust...	Reduced.....	24
		Rock hardness..	...do.....	
Calcium fluoride crystals ⁴	NA	NP.....	NE.....	31
Diabase ⁸	.17 - .22	Drilling costs.	Decreased.....	19
		Drilling rate..	Significantly increased	
Diorite ⁶	.02	...do.....	NE.....	19
Granite ⁴	.05	Amount drilled.	Increased.....	19
		Drilling rate..	...do.....	
		Drilling speed.	...do.....	
Do. ⁴	5×10^{-6}	Bit wear.....	Minimized.....	1, 14
		Rock hardness..	Maximized.....	
Granodiorite.....	.01 - .05	Drilling rate..	Increased.....	6
		Rock hardness..	Minimized.....	
Do.....	$11,005$	...do.....	...do.....	3
Gritstone ^{4,8}	.0 - .05	Drilling rate..	Increased 15 to 40 pct.	23
Do. ^{4,8}	.0075- .03	Drill thrust...	Reduced.....	23
		Rock hardness..	...do.....	
Hematite.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Igneous rocks ¹²	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Decreased.....	
		Rock strength..	Decreased 9 to 20 pct..	
Ironstone ⁸	.1 - .15	Amount drilled.	Increased.....	19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate..	Increased.....	
		Drilling speed.	...do.....	
Limestone ^{4,9}	.0 - .5	Bit wear.....	Reduced.....	23
		Drilling rate..	Increased 9 pct.....	

See notes at end of table.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
ALUMINUM CHLORIDE--Continued				
Magnesite.....	0.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Magnesium oxide crystals ⁴	NA	Drilling rate..	Increased.....	32
Marble ⁴	0.5 - 1.0	...do.....	NE.....	2
Martite.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Microcline ⁴	.0001- 1.0	NP.....	NE.....	29
Pyrite.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Quartz ⁸	.01 - .05	Drilling rate..	Increased.....	6
		Rock hardness..	Decreased.....	
Do. ⁸	.02 - .1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Do. ⁸	.7 - 1.0	Amount drilled.	Increased.....	19
		Bit wear.....	Decreased 34 pct.....	
		Drilling speed.	Increased.....	
Quartzite ^{8, 13}	.1 - .15	Amount drilled.	...do.....	19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate..	Increased.....	
		Drilling speed.	...do.....	19
Sandstone.....	.3	Bit wear.....	Decreased 28 to 42 pct ⁴	
		Drilling rate..	Increased ⁸	
		Dust.....	Decreased ⁸	23
Do. ⁴	.0 - .5	Bit wear.....	...do.....	
		Drilling rate..	Increased 15 to 40 pct.	
Do. ⁴	.0075- .03	Drill thrust...	Reduced.....	24
		Rock hardness..	Decreased.....	
Serpentine ⁴	.0001- 1.0	NP.....	NE.....	2
AMMONIUM NITRATE ⁶				
Granite.....	0.02	Amount drilled.	Increased.....	19
		Bit corrosion..	Extreme.....	
		Drilling rate..	Increased.....	
		Drilling speed.	...do.....	
ANIONIC DETERGENT ⁴				
Quartzite.....	4, 8, 12	Bit energy.....	Increased.....	28
		Bit friction...	...do.....	28
		Bit life.....	...do.....	21, 27
		Bit wear.....	Decreased.....	28
		Drilling costs.	Decreased 30 pct.....	27
		Drilling rate..	Increased.....	21, 28
		Overall efficiency.	Increased 60 pct.....	20
B.P.S.B.4 ¹⁴				
Granite.....	2.5	Bit life.....	Increased very markedly	9
Quartz.....				
Rhyolite.....				
Sandstone.....				
Tuff.....				

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
CALCIUM CHLORIDE				
Anhydrite ⁸	0.1 - 1.0	Bit wear..... Drilling speed.	Decreased 10 pct..... Increased 20 pct.....	18
Limestone.....	1.0	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	
CALCIUM HYDROXIDE				
Anhydrite.....	150.06	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	18, 30
Limestone.....	0.05 - .07	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	
Sandstone.....	.05 - .07	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30
Siderite ⁸	.05 - .07	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	
COMPOUND "M" ³				
Greenstone.....	0.2	Drilling effectiveness.	Increased.....	11
CONCO XAC, CONCO XAM, CONSOFT C, CONSOFT CP-50 ⁴				
CONCO XAC Rhyolite porphyry.....	0.032	} NP.....	NE.....	15
CONCO XAM Rhyolite porphyry.....	>1.0			
CONSOFT C Rhyolite porphyry.....	<.001			
CONSOFT CP-50 Rhyolite porphyry.....	.0016			
CUTALL OIL ³				
Greenstone.....	20.0	Drilling effectiveness.	Increased.....	11
DIMETHYLFORMAMIDE (DMF), DIMETHYLSULFOXIDE (DMSO), DMF IN DMSO ⁴				
DMF				
Calcium fluoride crystals.....	0 -100	Rock hardness..	Reduced.....	31-32
Lithium fluoride crystals ⁹	NA	Bit life.....	Increased.....	13
Magnesium oxide crystals.....	0 -100	Drilling rate..	...do.....	15, 32
DMSO				
Calcium fluoride crystals.....	0 -100	Rock hardness..	Reduced.....	31-32
Magnesium oxide crystals.....	0 -100	Drilling rate..	Increased.....	32
DMF IN DMSO				
Calcium fluoride crystals.....	0 - 50	Rock hardness..	Reduced.....	31-32
Magnesium oxide crystals.....	50	Drilling rate..	Increased 20 times....	8, 32
		Rock hardness..	Decreased.....	31
DISOLVANE 4411				
Coal ¹⁶	NA	NP.....	NE.....	22
DODECYLAMINO ACETATE ⁸				
Quartz.....	NA	Bit wear.....	Decreased 2 to 3 times.	25
See notes at end of table.				

See notes at end of table.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
DODECYLTRIMETHYL AMMONIUM BROMIDE (DTAB)				
Granite ⁴	⁵ 10 ⁻⁴ - 10 ⁻³	Bit life..... Drilling costs. Drilling rate..	Increased..... Reduced..... Increased 3 to 4 times.	} 8, 12, 14- 15, 17, 32
Microcline.....	⁵ 10 ⁻⁴ - 10 ⁻³	...do.....	Increased.....	
Quartz ⁴	⁵ 10 ⁻⁴ - 10 ⁻³	Bit life..... Drilling costs. Drilling rate..	Increased 4-fold..... Reduced..... Increased 20-fold.....	
DROMUS B				
Argillaceous rocks: ¹⁷				
Hard shales.....	0.91	Bit life.....	Increased very markedly	} 9
Soft shales.....	.13	Drilling rate..	...do.....	
Hard shales.....	.67	Bit wear.....	Reduced.....	} 10
Very soft shales.....	.17	Drilling rate..	Increased.....	
		Drill vibration	Eliminated.....	
		Lifting action.	Improved.....	
		Pump pressures.	Reduced.....	
Chert: ¹⁷				
Hard.....	.91	Bit life.....	Increased very markedly	} 9
Soft.....	.13	Drilling rate..	...do.....	
		Rod grease.....	Not required.....	
Coal ¹⁸	1.0	Bit life..... Drilling rate.. Rod grease.....	Increased markedly.... Increased slightly.... Required.....	} 9
Dolomite ¹⁷	0.13 - .91	Bit life..... Drilling rate.. Rod grease.....	Increased markedly.... ...do..... Not required.....	
Do. ⁸	.67	Bit wear..... Drilling rate.. Drill vibration Lifting action. Pump pressures.	Decreased..... Increased..... Eliminated..... Improved..... Reduced.....	} 10
Ironstone: ¹⁷				
Hard.....	.91	Bit life.....	Increased very markedly	
Soft.....	.13	Bit wear.....	Decreased.....	
		Drilling rate..	Increased very markedly	
		Drill vibration	Eliminated.....	10
		Lifting action.	Improved.....	10
		Pump pressures.	Reduced.....	10
Ironstone (jaspilite) ¹⁹	NA	Bit life..... Drilling rate.. Rod grease.....	Increased very markedly Increased markedly.... Not required	} 9
Quartzite: ¹⁷				
Hard.....	.91	Bit life.....	Increased very markedly	
Soft.....	.13	Bit wear.....	Decreased.....	9-10
		Drilling rate..	Increased very markedly	9-10
		Drill vibration	Eliminated.....	10
		Lifting action.	Improved.....	10
		Pump pressures.	Reduced.....	10
Riebeckites ⁸	.91	Bit wear..... Drilling rate.. Drill vibration Lifting action. Pump pressures.	Decreased..... Increased..... Eliminated..... Improved..... Reduced.....	} 9
DROMUS B PLUS ESSO 1 ¹⁷				
Chert.....	5 - 7	Bit life..... Drilling rate.. Rod grease.....	Increased very markedly ...do..... Not required.....	} 9

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²	
DROMUS B PLUS ESSO 1--Continued ¹⁷					
Granite.....	5 - 7	Bit life..... Drilling rate..	Increased very markedly ...do.....	9	
Quartz.....	5 - 7	Bit life..... Drilling rate.. Rod grease.....	...do..... ...do..... Not required.....		9
DUOMAC T ⁴					
Rhyolite porphyry.....	<0.001	NP.....	NE.....	15	
ETHYL ALCOHOL					
Dolomite.....	NA	Drilling rate..	Increased 70 pct.....	20	
ETHYLENE GLYCOL ⁴					
Quartzite.....	4, 8, 12	Bit energy..... Bit friction... Bit life..... Bit wear..... Drilling costs. Drilling rate..	Increased..... ...do..... ...do..... Decreased..... Decreased 30 pct..... Increased.....	28 28 21, 27 28 27 21, 28	
FERRIC CHLORIDE					
Hematite.....	0.1	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30	
Magnesite.....	.1	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30	
Martite.....	.1	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30	
Pyrite.....	.1	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30	
Quartzite ^{8, 15}	.48	Amount drilled. Bit wear..... Drilling rate.. Drilling speed.	Increased..... Decreased 26 pct..... Increased..... ...do.....	19	
GLYCERINE ⁴					
Quartzite.....	4, 8, 12	Bit energy..... Bit friction... Bit life..... Bit wear..... Drilling costs. Drilling rate..	Increased..... ...do..... ...do..... Decreased..... Decreased 30 pct..... Increased.....		28 28 21, 27 28 27 21, 28
HETOXAMINE C-10 ⁴					
Rhyolite porphyry.....	0.0016	NP.....	NE.....	15	
HYDROCHLORIC ACID					
Argillaceous rocks (shales) ⁴	0.0 - 0.5	Bit wear..... Drilling rate..	Reduced..... Increased 15 to 40 pct.	23	
Dolomite.....	<1.0	Bit wear..... Drilling speed. Rock hardness..	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....		18
Gritstone ^{4, 9}	.0 - .5	NP.....	NE.....	23	
Limestone ^{8, 20}	1.0	Bit wear..... Drilling speed.	Decreased 10 pct..... Increased 10 to 70 pct.	18	

See notes at end of table.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
HYDROCHLORIC ACID--Continued				
Limestone ²⁰	0.1 - 0.3	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	19
Do. ^{4,9,20}	.0 - .5	Bit wear..... Drilling rate..	Reduced..... Increased 9 pct.....	
Sandstone ⁴	.0 - .5	Bit wear..... Drilling rate..	Decreased..... Increased 15 to 40 pct.	
INTERSOFT 49 ⁴				
Rhyolite porphyry.....	0.001	NP.....	NE.....	15
KEROSENE				
Greenstone ⁵	Pure	Drilling effectiveness.	Increased.....	11
Quartz ⁶	Pure	Bit friction... Bit wear.....	Decreased 7 times..... Decreased 40 times.....	25
LIME				
Sandstone.....	0.05 - 0.07	Bit wear..... Drilling rate..	Decreased 10 to 35 pct.. Increased 20 to 60 pct.	26
MAGNESIUM CHLORIDE				
Argillaceous rocks (shales) ⁴	0.0 - 0.3	Bit wear..... Drilling rate..	Reduced..... Increased 15 to 40 pct.	23
Diabase ⁸	.75 - 1.5	Drilling costs. Drilling rate..	Decreased..... Slightly increased.....	
Granite ¹³	.01	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	19
Granodiorite.....	.01 - .05	Drilling rate.. Rock hardness..	...do..... Minimized.....	
Do. ^{8,13}	.9 - 1.5	Drilling rate..	Increased.....	19
Do.....	¹¹ .05	Rock hardness..	Minimized.....	3
Gritstone ^{4,9}	.0 - .3	NP.....	NE.....	23
Ironstone ⁸	.3	Amount drilled. Bit wear..... Drilling rate.. Drilling speed.	Increased..... Decreased 26 pct..... Increased..... ...do.....	19
Limestone.....	²¹ .25 - 1.0	Amount drilled. Drilling rate.. Drilling speed.	...do..... ...do..... ...do.....	
Do. ^{4,9}	.0 - .3	Bit wear..... Drilling rate..	Reduced... Increased 9 pct.....	23
Marble ⁴	NA	...do.....	NE.....	
Microcline ⁴	.0001- 1.0	NP.....	NE.....	29
Quartz ⁸	.01 - .5	Drilling rate.. Rock hardness..	Increased..... Decreased.....	6
Do. ⁸	.1 - .5	Bit wear..... Drilling rate..	Decreased 10 to 35 pct.. Increased 20 to 60 pct.	
Quartzite ^{8,13}	.3	Amount drilled. Bit wear..... Drilling rate.. Drilling speed.	Increased..... Decreased 26 pct..... Increased..... ...do.....	19
Sandstone ⁴	.0 - .3	Bit life..... Bit wear..... Drilling rate..	...do..... Decreased..... Increased 15 to 40 pct.	
MAGNESIUM SULFATE				
Diabase ⁸	0.25	Drilling costs. Drilling rate..	Decreased..... Slightly increased.....	19
Limestone.....	0.75 - 1.0	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²	
MARVANSOFT FBH, MARVANSOFT FMA ⁴					
MARVANSOFT FBH Rhyolite porphyry.....	0.25	Bit life..... Drilling costs..	Increased 5-fold..... Decreased 50 pct.....	15	
MARVANSOFT FMA Rhyolite porphyry.....	.025	NP.....	NE.....		
MOBIL 1535 ²²					
Greenstone.....	4.0	Bit life..... Drilling rate..	NE.....	9	
Porphyry.....	4.0	NP.....			
Quartzite.....	4.0	Bit life..... Drilling rate..			
MUD ⁴					
Granite..... Limestone..... Marble..... Sandstone.....	(23)	Bit wear.....	Reduced.....	7	
N-ALCOHOLS					
Granite.....		(24)	NP.....	NE.....	12, 32
Quartz ⁴		NA	Drilling rate.. ...do.....	Increased 20-fold..... NE.....	8 29
N-ALKANES ⁴					
Calcium fluoride crystals.....	NA	Drilling rate..	Increased.....	31	
Magnesium oxide crystals.....	NA	...do.....	Increased 8 times using hexadecane.	20, 32	
NAPHTHENIC ACID SOAP					
NAPHTHENIC ACID SOAP ⁸ Quartz.....	NA	Bit wear..... Drilling rate..	Decreased 10 to 35 pct.. Increased 20 to 60 pct..	26	
NAPHTHENIC ACID SOAP PLUS SODIUM CARBONATE ²⁵ Granite.....	150.25 - 0.5 .25	Bit wear..... Drilling rate..	Decreased 10 to 35 pct.. Increased 20 to 60 pct..		
NAPHTHENIC OIL					
NAPHTHENIC OIL Quartz.....	0.25 - 0.5	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30	
NAPHTHENIC OIL PLUS SODIUM CARBONATE Quartz.....	26.25	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..		
OIL SOAP					
Limestone.....	0.1 - 1.0	Amount drilled. Drilling rate.. Drilling speed..	Increased..... ...do..... ...do.....	19	
Sandstone ⁸	.1	Drilling rate.. Dust.....	...do..... Decreased.....		
OLEYLAMMONIUM ACETATE					
Amygdaloidal basalt ²⁷	150.01	Drilling costs. Drilling rate..	Reduced..... Increased 20 to 50 pct.	4	
Quartz ⁴	.7	...do.....	Increased 50 pct.....		
See notes at end of table.					

See notes at end of table.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²	
OP-10					
Coal ¹⁶	0.05 - 0.12	Bit life..... Bit wear..... Drilling rate..	Increased..... Decreased..... Increased.....	22	
PETROLEUM SULFONATE ⁸					
Quartz.....	0.25 - 0.5	Bit wear..... Drilling rate..	Decreased 10 to 35 pct. Increased 20 to 60 pct.		26
POTASSIUM CHLORIDE ⁸					
Quartz.....	0.01 - 0.5	Bit wear..... Drilling rate..	Decreased 10 to 35 pct. Increased 20 to 60 pct.	26	
QUAT 316 ⁴					
Marble.....	⁵ 10 ⁻³ - 10 ⁻²	Drilling rate..	NE.....	2	
SMAD ⁸					
Argillaceous rocks (shales).....	NA	NA.....	NE.....	5	
Sandstone.....	NA	Bit friction... Rock strength.. Torsional moment.	Decreased..... ...do..... ...do.....	5	
SNS					
Coal ¹⁶	NA	NP.....	NE.....		22
SOAP ⁴					
Marble.....	0.25 - 0.5	Drilling rate..	NE.....	2	
SODIUM CARBONATE					
Anhydrite ⁸	0.1 - 1.0	Bit wear..... Drilling speed.	Decreased 10 pct..... Increased 20 pct.....	18	
Argillaceous rocks: Shales.....	.25	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..		30
Do. ⁸	NA	Amount drilled. Drilling rate.. Drilling speed. Overall efficiency.	Slightly increased.... ...do..... ...do..... Increased.....	19	
Do. ⁴	²¹ 0 - .5	Bit wear..... Drilling rate..	Decreased..... Increased 15 to 40 pct.		
Argillites and schists.....	.1 - .25	Bit wear..... Drilling rate..	Decreased 10 to 35 pct. Increased 20 to 60 pct.	26	
Diabase ⁸	.75	Drilling costs. Drilling rate..	Decreased..... Slightly increased....		
Diorite ⁸	.5	...do.....	NE.....	19	
Granite ⁸	.25	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	19	
Granodiorite.....	.01 - .1	Drilling rate.. Rock hardness..	...do..... Minimized.....		6
Gritstone ^{4,9}	.0 - .5	NP.....	NE.....	23	
Limestone ⁸	.25	Amount drilled. Bit life..... Bit wear..... Drilling rate.. Drilling speed. Rock hardness.. Rock strength..	Increased..... ...do..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Increased..... Decreased..... Decreased 9 to 20 pct..	19 30 26, 30 19, 26, 30 19 30 30	
Do. ⁸	.1 - 1.0	Bit wear..... Drilling speed.	Decreased 10 pct..... Increased 10 to 70 pct.	18	

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²		
SODIUM CARBONATE--Continued						
Limestone ⁸	0.0 - 0.5	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	19		
Do. ^{4,9}	.0 - .5	Bit wear..... Drilling rate..	Reduced..... Increased 9 pct.....		23	
Marble ⁴	.2 - 1.0	...do.....	NE.....			
Quartz ⁸	.01 - .1	Drilling rate.. Rock hardness..	Increased..... Decreased.....	6		
Sandstone.....	.25	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..		30	
Do.....	.3 - .5	Bit wear..... Drilling costs. Drilling speed. Dust.....	Decreased 2.5 times.... Slightly reduced..... Increased 4 times..... Decreased.....	19		
Do. ⁴	.0 - .5	Bit wear..... Drilling rate..	...do..... Increased 15 to 40 pct.			23
Siderite ⁸	.25	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..			
SODIUM CARBONATE PLUS SOAP						
Igneous rocks ¹²	.26, .25	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30		
SODIUM CHLORIDE						
Anhydrite ⁸	0.1 - 1.0	Bit wear..... Drilling speed.	Decreased 10 pct..... Increased 20 pct.....		18	
Argillaceous rocks: Shales, argillites and schists, clay rocks.	.25 - .5	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..			30 26, 30 26, 30 30 30
Shales ⁸	.25	Amount drilled. Drilling rate.. Drilling speed. Overall efficiency.	Slightly increased..... ...do..... ...do..... Increased.....		19	
Do. ⁸	1.0 - 2.0	Amount drilled. Drilling rate.. Drilling speed. Overall efficiency.	Slightly increased..... ...do..... ...do..... Increased.....	19		
Do. ⁴	.28, .0 - 3.5	Bit wear..... Drilling rate..	Reduced..... Increased 15 to 40 pct.			23
Diabase ⁸	.4 - 1.0	Drilling costs. Drilling rate..	Decreased..... Slightly increased....	19		
Diorite ⁸	.2	...do.....	Increased.....	19		
Granite ⁸	.1 - .5	Amount drilled. Drilling rate.. Drilling speed.	...do..... ...do..... ...do.....	19		
Granodiorite ^{8,13}	1.0	Drilling rate..	...do.....		19	
See notes at end of table.						

See notes at end of table.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
SODIUM CHLORIDE--Continued				
Granodiorite.....	0.1	Drilling rate..	Increased.....	6
		Rock hardness..	Minimized.....	
Do.....	¹¹ .05	...do.....	...do.....	3
Gritstone ^{4,9}	0.0 - 3.5	NP.....	NE.....	23
Hematite.....	.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Igneous rocks ¹²	.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Decreased.....	
		Rock strength..	Decreased 9 to 20 pct..	
Ironstone ⁸	.25	Amount drilled.	Increased.....	19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate..	Increased.....	
		Drilling speed.	...do.....	
Limestone ⁸	.25	Bit life.....	...do.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Do.....	.75	Amount drilled.	Increased.....	19
		Drilling rate..	...do.....	
		Drilling speed.	...do.....	
Do. ^{4,9}	²⁸ .0 - 3.5	Bit wear.....	Reduced.....	23
		Drilling rate..	Increased 9 pct.....	
Magnesite.....	.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Magnesium oxide crystals ⁴	¹¹ 10 ⁻²	Bit life.....	Increased 5 times.....	13
		Drilling rate..	Increased.....	8
Martite.....	.1 - .25	Bit life.....	...do.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Porphyry ⁸	.1 - .25	Amount drilled.	Increased.....	19
		Drilling rate..	...do.....	
		Drilling speed.	...do.....	
		Dust.....	Decreased.....	
Pyrite.....	.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Do. ^{4,8}	.1 - .5	Drilling speed.	Increased.....	19
Quartz ⁸	.1 - .5	Bit life.....	...do.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Do. ⁸	.1	Drilling rate..	Increased.....	6
		Rock hardness..	Decreased.....	
Quartzite ^{8,13}	.25	Amount drilled.	Increased.....	19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate..	Increased.....	
		Drilling speed.	...do.....	

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
SODIUM CHLORIDE--Continued				
Sandstone.....	0.25	Amount drilled ⁴	Increased.....	19
		Bit life.....	...do.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	19, 26, 30
		Drilling speed ⁴	Increased.....	19
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Do. ⁴	0.0 - 3.5	Bit wear.....	Decreased.....	23
		Drilling rate..	Increased 15 to 40 pct.	
SODIUM CHLORIDE PLUS SODIUM CARBONATE				
Argillaceous rocks (clay rocks).	0.1 - 0.5	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Decreased.....	
		Rock strength..	Decreased 9 to 20 pct..	
Sandstone.....	26, 25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct...	30
SODIUM HYDROXIDE				
Anhydrite.....	150.05 - 0.1	Bit life.....	Increased.....	18, 30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Decreased.....	
		Rock strength..	Decreased 9 to 20 pct..	
Do. ⁸	.1 - .2	Amount drilled.	Increased.....	19
		Drilling rate..	...do.....	
		Drilling speed.	...do.....	
Limestone.....	.05	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Decreased.....	
		Rock strength..	Decreased 9 to 20 pct..	
Do.....	.1 - .2	Amount drilled.	Increased.....	19
		Drilling rate..	...do.....	
		Drilling speed..	...do.....	
Marble ⁴	.025 - .25	Drilling rate..	NE.....	2
Quartz ⁸	.1 - 1.0	Bit wear.....	Decreased 10 pct.....	18
		Drilling speed.	Increased 20 pct.....	
SODIUM HYDROXIDE PLUS SODIUM CARBONATE				
Dolomite.....	0.06 - 0.2	Amount drilled.	Increased.....	19
		Bit wear.....	Decreased 54 pct.....	
		Drilling rate..	Increased.....	
		Drilling speed.	Slightly increased.....	
Limestone.....	.05 - .2	Amount drilled.	Increased.....	19
		Drilling rate..	...do.....	
		Drilling speed.	...do.....	
SODIUM OLEATE ⁸				
Quartz.....	NA	Bit wear.....	Decreased 2 to 3 times.	25
SODIUM ORTHOPHOSPHATE ⁸				
Quartz.....	1.0 - 2.0	Bit wear.....	Decreased 10 pct.....	18
		Drilling speed.	Increased 20 pct.....	
		Rock hardness..	Decreased 60 to 70 pct.	
SODIUM PHOSPHATE ⁸				
Limestone.....	0.1	Bit wear.....	Decreased 10 to 35 pct.	26
		Drilling rate..	Increased 20 to 60 pct.	

See notes at end of table.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²	
SODIUM PYROPHOSPHATE ⁸					
Quartz.....	1.0 - 2.0	Bit wear..... Drilling speed.. Rock hardness..	Decreased 40 pct..... Increased 20 pct..... Decreased 60 to 70 pct.	18	
SODIUM SILICATE ⁸					
Limestone.....	0.025	Bit wear..... Drilling rate..	Decreased 10 to 35 pct.. Increased 20 to 60 pct.		26
SOLAR CL-385 ⁴					
Rhyolite porphyry.....	<0.001	NP.....	NE.....	15	
SOLVAC ²²					
Garnetite.....	1.0	Bit life..... Drilling rate.. Rod grease.....	Increased markedly..... Increased very markedly Not required.....	9	
Quartzite.....	1.0	Bit life..... Drilling rate..	Increased very markedly ...do.....		9
SUGAR					
Granodiorite.....	0.1 - 1.0	Drilling rate.. Rock hardness..	Increased..... Minimized.....	6	
Quartz ⁸	.1 - 1.0	Drilling rate.. Rock hardness..	Increased..... Decreased.....		6
SULFANOL ⁸					
Argillaceous rocks (shales).....	0.05 - 0.15	Bit energy..... Bit friction... Drilling rate.. Rock strength..	Decreased..... ...do..... Increased..... Decreased.....	5	
Sandstone.....	.05 - .15	Bit energy..... Bit friction... Drilling rate.. Rock strength..	...do..... ...do..... Increased..... Decreased.....		5
SULFATE SOAP ⁸					
Argillaceous rocks (shales).....	NA	NA.....	NE.....	5	
Sandstone.....	NA	Bit friction... Rock strength.. Torsional moment.	Decreased..... ...do..... ...do.....	5	
SULFITE CELLULOSE LYE					
Dolomite.....	50	Bit wear..... Drilling speed.. Rock hardness..	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....	18	
Limestone ⁸	50	Bit wear..... Drilling speed.. Rock hardness..	Decreased 10 pct..... Increased 10 to 70 pct.. Decreased 30 to 50 pct.		18
SULFONAPHTHENIC PETROLEUM ACIDS					
Dolomite.....	1 - 2	Bit wear..... Drilling speed.. Rock hardness..	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....	18	
Limestone ⁸	1 - 2	Bit wear..... Drilling speed.. Rock hardness..	Decreased 10 pct..... Increased 10 to 70 pct.. Decreased 30 to 50 pct.		18
TERGITOL ²⁷					
Amygdaloidal basalt.....	0.1	Drilling costs. Drilling rate..	Reduced..... Increased 20 to 50 pct.	4	
Amygdaloidal basalt.....	.1	Drilling costs. Drilling rate..	Reduced..... Increased 20 to 50 pct.		4

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
THORIUM CHLORIDE ⁴				
Argillaceous rocks (shales).....	0.0 - 0.03	Bit wear..... Drilling rate..	Reduced..... Increased 15 to 40 pct.	23
Gritstone ⁹	.0 - .03	NP.....	NE.....	
Limestone ⁹	.0 - .03	Bit wear..... Drilling rate..	Reduced..... Increased 9 pct.....	23
Sandstone.....	.0 - .03	Bit wear..... Drilling rate..	Decreased..... Increased 15 to 40 pct.	
TOLUENE ⁴				
Calcium fluoride crystals.....	NA	NP.....	NE.....	31
Lithium fluoride crystals ⁹	NA	Bit life.....	Increased.....	13
Magnesium oxide crystals.....	Pure	Drilling rate..	...do.....	15, 32
Quartz.....	Pure	...do.....	Increased 20-fold.....	8
TORQUE TRIM ⁴				
Rhyolite porphyry.....	2.0	NP.....	NE.....	15
WATER ²⁹				
Greenstone ³	Nap	Drilling effectiveness.	Increased to maximum...	11
Lithium fluoride crystals ^{4,9}	Nap	Bit life.....	Increased.....	13
Magnesium oxide crystals ⁴	Nap	Drilling rate..	NE.....	15
Quartz ⁴	Nap	...do.....	Increased 20-fold.....	8
Quartzite ⁴	Nap	NP.....	NE.....	21

NA Not available. Nap Not applicable.

NE No added effects reported. NP No specific property reported.

¹Compared to drilling with water alone.²Numbers refer to items in the list of references preceding the appendixes.³Field test using EX (1.5-in-ID) bit.⁴Laboratory test(s). ⁵Mole per liter.⁶Tests on hematite and taconite. ⁷Test using BX (2.375-in-ID) bit.⁸Field test(s), no bit size given. ⁹Compared to dry drilling, not to water.¹⁰Optimum reported concentration was 0.01 pct. ¹¹Normal concentration (N).¹²Recommended for all low-silica, igneous rocks. ¹³Industrial tests.¹⁴Field test using BX (2.375-in-ID) bit and NX (3.0-in-ID) bit.¹⁵Optimum reported concentration.¹⁶Novo Khazinskii and Arlanskii coal deposits, Arlansk region, field tests.¹⁷Field test using NX (3.0-in-ID) bit.¹⁸New South Wales coal measure, field tests.¹⁹Field test using AX (1.91-in-ID) bit and BX (2.375-in-ID) bit.²⁰Reported that the reactant fluid, calcium chloride, produced the enhanced results.²¹Optimum reported concentration was 0.25 pct.²²Field test using AX (1.91-in-ID) bit.²³Composition of special mud, in percent:

Bentonite clay..... 5.6

Sodium bicarbonate.. .95

Sodium chloride..... 13.4

Tap water..... 80.05

²⁴Methane to decanol.²⁵Naphthenic acid soap, 0.25 to 0.5 wt pct; sodium carbonate, 0.25 wt pct.²⁶Each. ²⁷Field test using AXL (1.185-in-ID) bit.²⁸Optimum reported concentration was 0.1 pct.²⁹Water used as drilling fluid, not just for comparison purposes.

REFERENCES³

1. Appl, T. C., B. N. Rao, and B. H. Walker. Effects of $AlCl_3$ Additive While Cutting Granite With a Single Diamond. *Ind. Diamond Rev.*, v. 41, June 1981, pp. 312-318.
2. Cooper, G. A., and J. Berlie. On the Influence of the Flushing Fluid During Diamond Drilling. *J. Mater. Sci.*, v. 11, 1976, pp. 1771-1775.
3. Efimov, M. V. (Fixation (Adsorption) of Softeners With Ore in Relation to Their Concentrations.) *J. Appl. Chem. (Leningrad)*, v. 13, 1940, pp. 1336-1340; *Chem. Abstr.*, v. 35, 1941, No. 2245.5.
4. Engelmann, W. H., H. F. Unger, and B. S. Snowden. Diamond Drilling With Surfactants in Upper Michigan Amygdaloidal Basalts Using Surface-Set Bits. *Trans. Soc. Min. Eng. AIME*, v. 258, Sept. 1975, pp. 185-190.
5. Epshtein, E. F., and A. N. Davidenko. (Effect of the Medium on the Destruction of Rocks.) *Izv. Vyssh. Uchebn. Zaved., Gorn. Zh.*, v. 7, 1980, pp. 3-5; *Chem. Abstr.*, v. 93, 1980, No. 242175y.
6. Golovanov, N. I. (Application of the Ore Softeners for Accelerating of Drilling of Quartz and Granodiorite Strata of the Kochkar' Deposit.) *Gorn. Zh.*, v. 114, Nos. 8-9, 1938, pp. 22-25; *Chem. Abstr.*, v. 33, 1939, No. 1411.3.
7. Hoenig, S. A., R. Zanoni, and J. L. Griffith. Application of Electrochemical Technology to the Improvement of Rock-Drilling Systems. *Wear*, v. 86, 1983, pp. 247-256.
8. Jackson, R. E., N. H. Macmillan, and A. R. C. Westwood. Chemical Enhancement of Rock Drilling. Paper in *Advances in Rock Mechanics (Proc. 3d Congr. Int. Soc. Rock Mech., Denver, CO, Sept. 1-7, 1974)*. Reports of Current Research, v. 2, pt. B. *Natl. Acad. Sci.*, Washington, DC, 1974, pp. 1487-1492.
9. Joris, A. C. T., and G. McLaren. Additives to Coolants Used in Diamond Drilling and Sawing in Australia. *Min. and Miner. Eng.*, v. 3, No. 5, May 1967, pp. 190-205.
10. Kitching, J. Major Advance in Drilling Technique Reported From Wittenoom Gorge. *Min. and Chem. Eng. Rev.*, v. 57, No. 2, Feb. 1965, pp. 11-13.
11. Long, A. E., and W. G. Agnew. Effect of Lubricating Agents in a Diamond-Drilling-Bit Coolant and Cuttings-Removal Medium. *BuMines RI 3793*, Jan. 1945, 5 pp.
12. Macmillan, N. H., R. E. Jackson, W. M. Mularie, and A. R. C. Westwood. Optimization of Fluids for Diamond Core Drilling of Silicates. *Trans. Soc. Min. Eng. AIME*, v. 258, Dec. 1975, pp. 278-280.
13. Martin Marietta Corp. (Baltimore, MD). Application of Chemomechanical Effects to Full-Scale Hard Rock Drilling. *MML Prop. MA 77-04R*, Jan. 1977, 100 pp.
14. Mills, J. J. Environment-Enhanced Disintegration of Hard Rocks. *Martin Marietta Corp., Baltimore, MD, MML Tech. Rep. 76-90c*, Nov. 1976, 35 pp.
15. _____. Environment-Enhanced Disintegration of Hard Rocks. *Martin Marietta Corp., Baltimore, MD, MML Tech. Rep. 78-10c*, Feb. 1978, 76 pp.
16. _____. Letters. Influence of Chemomechanically Active Fluids on Diamond Wear During Hard Rock Drilling. *J. Mater. Sci.*, v. 13, 1978, pp. 2712-2716.
17. Mills, J. J., A. R. C. Westwood, and R. D. Huntington. Environment-Enhanced Disintegration of Hard Rocks. *Martin Marietta Corp., Baltimore, MD, MML Tech. Rep. 76-40c*, May 1976, 31 pp.
18. Rebinder, P. A., L. A. Shreiner, and K. F. Zhigach. (Decreasing the Hardness of Strata by Adding Chemical Compounds to the Drilling Fluid Thus Increasing the Drilling Velocity.) *Neft. Prom. SSSR*, No. 5, 1940, pp. 54-65; *Chem. Abstr.*, v. 36, 1942, No. 1471.4.
19. _____. (Hardness Reducers in Drilling. A Physico-Chemical Method of Facilitating the Mechanical Destruction of Rocks During Drilling.) *Akad. Nauk SSSR, Moscow*, 1944; *Transl. by Commonw. Sci. and Ind. Res. Organ. (CSIRO)*, Melbourne, Australia, 1948, 163 pp.

³Additional references are included in each appendix.

20. Research Institute for Advanced Studies (Baltimore, MD). Environment-Enhanced Disintegration of Hard Rocks. RIAS Prop. 412, Mar. 1972, 60 pp.
21. Selim, A. A., C. W. Schultz, and K. C. Strebis. The Effect of Additives on Impregnated Diamond Bit Performance. Soc. Pet. Eng. J., v. 13, 1969, pp. 425-433.
22. Sentsova, E. P. (Effects of Surfactants on the Drilling Rate During the Opening of a Producing Horizon in the Arlansk Deposit.) Soversh. Vskrytiya, Ispyt. i Osvoeniya Prod. Plastov Ekspl. i Razved. Skvazhinakh., Mater. Vses. Soveshch., 1966, pp. 154-157; Chem. Abstr., v. 72, 1970, No. 14486m.
23. Shepherd, R. Improving the Efficiency of Rotary Drilling of Shotholes. Trans. Inst. Min. Eng., v. 113, pt. 11, Aug. 1954, pp. 1029-1048.
24. _____. Rotary Drilling Developments. Mine and Quarry Eng., v. 21, No. 8, Aug. 1955, pp. 329-335.
25. Shreiner, L. A., and K. M. Sadilenko. (Physical and Chemical Influence of Liquid Mediums on the Wear of Steel and Hard Alloys During Friction on Rocks.) Dokl. Akad. Nauk SSSR, v. 139, No. 2, 1961, pp. 427-429; Chem. Abstr., v. 61, 1964, No. 367g.
26. Shreiner, L. A., and K. F. Zhigach. (Boring Holes With Flushing in Conjunction With Agents for Decreasing the Hardness of Rocks.) Akad. Nauk SSSR, Kolloido-Elektrokhim. Inst., 1943, 63 pp.; Chem. Abstr., v. 38, 1944, No. 1815.
27. Strebis, K. C., C. W. Schultz, and A. A. Selim. How To Effect a Cost Reduction in Diamond Drilling. Min. Eng. (N.Y.), v. 21, Oct. 1969, pp. 73-75.
28. Strebis, K. C., A. A. Selim, and C. W. Schultz. Effect of Organic Additives on Impregnated Diamond Drilling. BuMines RI 7494, 1971, 31 pp.
29. Tweeton, D. R., W. H. Engelmann, G. A. Savanick, and D. I. Johnson. Influence of Surface-Active Chemicals on Drilling and Fracturing Rock. BuMines RI 8186, 1976, 20 pp.
30. Vutukuri, V. S. Improved Drilling Rates at Lower Cost. Min. Mag., v. 125, No. 4, Oct. 1971, pp. 324-327.
31. Westwood, A. R. C., and D. L. Goldheim. Mechanism for Environmental Control of Drilling in MgO and CaF₂ Monocrystals. J. Am. Ceram. Soc., v. 53, 1970, pp. 142-147.
32. Westwood, A. R. C., N. H. Macmillan, and R. S. Kalyoncu. Chemomechanical Phenomena in Hard Rock Drilling. Trans. Soc. Min. Eng. AIME, v. 256, June 1974, pp. 106-111.

APPENDIX A.--SUMMARY OF CHEMICAL ADDITIVES USED TO STUDY
VARIOUS PROCESSING METHODS, WITH REFERENCES

TABLE A-1. - Chemical additives tested for various processing methods

Additive	Concentrations tested	Method ¹	References ²
ALUMINUM CRYSTALS			
Aeropromoter 765.....wt pct..	0.25-0.75	C	5
Aeropromoter 765 plus naphthenic acid.....wt pct..	0.2-0.8	C	5
Naphthenic acid.....wt pct..	0.25-0.75	C	5
Oleic acid.....wt pct..	0.25-0.5	C	5
Organosilicon.....wt pct..	0.005	C	3
CALCITE			
Sodium petroleum sulfonates.....	NA	Fl	1
CASSITERITE			
Alphaamino valeric acid.....	NA	Fl	17
Cupferron.....	NA	Fl	17
Laurylamine hydrochloride.....mg/L..	50	Fl	17
Sodium laurate.....	NA	Fl	17
Sodium oleate.....	NA	Fl	17
Sodium pelargonite.....	NA	Fl	17
Sodium sulfate.....mg/L..	50	Fl	17
CEMENT AND/OR CLINKER			
Acetone.....	Vapor	C	12
Asphaltines.....	NA	C	3
Benzene.....	Vapor	C	12
Calcium sulfate.....	NA	C	3
Carbon blacks.....	NA	C	3
Cod oil.....	NA	C	3
Cyclohexane.....	Vapor	C	12
Diethanolamine.....wt pct..	0.1	C	3
Ethylene glycol.....	Vapor	C	12
Glycol.....	NA	C	3
Kojic oil.....	NA	C	3
n-butylamine.....	Vapor	C	12
Organosilicon.....wt pct..	0.01-0.05	C	3
Propylene glycol.....wt pct..	0.05	C	3
Resins.....	NA	C	3
Triethanolamine.....wt pct..	0.1	C	3, 11, 15
Urea.....	NA	C	3
Water.....	NAP	C	3, 11, 15
Wool grease.....	NA	C	3
CLAY ROCKS			
Sodium chloride.....wt pct..	0.25-0.5	Fr	4
Soluble oils.....wt pct..	0.17	Fr	4
COAL			
Acetone.....	NA	C	2
Anhydrous ethanol.....	NA	C	2
Anhydrous isopropanol.....	NA	C	2
Anhydrous methanoo.....	NA	C	2
Dimethylsulfoxide.....	NA	Fr	18
Distilled water.....	NAP	Fr	18
Ethylamine.....	NA	C	2
Glacial acetic acid.....	NA	C	2
Hexadecane.....	NA	Fr	18
Hexanes.....	NA	Fr	18
Hydrogen peroxide.....	NA	C	2
Liquid ammonia.....	NA	C	2
Methanol.....	NA	C	2
Methyl amine.....	NA	C	2

See notes at end of table.

TABLE A-1. - Chemical additives tested for various processing methods--Con.

Additive	Concentrations tested	Method ¹	References ²
COAL--Continued			
Oleic acid.....	NA	Fr	18
Potassium iodine.....	NA	Fr	18
Saturated aluminum chloride.....mol..	2.49	Fr	18
Saturated calcium chloride.....mol..	2.34	Fr	18
Saturated iron chloride.....mol..	3.42	Fr	18
Saturated sodium chloride.....mol..	5.39	Fr	18
Sodium hydroxide.....	NA	C	2
Sodium silicate.....	NA	Fr	18
Toluene.....	Pure	Fr	18
CORUNDUM			
Sodium chloride.....	NA	Fl	17
Sodium nitrate.....	NA	Fl	17
DOLOMITE			
Calcium hydroxide.....wt pct..	0.05-0.07	Fr	4
Sodium hydroxide.....wt pct..	0.05	Fr	4
Soluble oils.....wt pct..	0.67	Fr	4
GLASS			
Acetone.....	NA	C	3
Benzene.....	NA	C	3
Carbon tetrachloride.....	NA	C	3
Nitromethane.....	NA	C	3
GYPSUM			
Wool grease.....	NA	C	3
HEMATITE (TACONITE)			
Activator AR calcium chloride.....lb/ton..	5-20	C	14
Aluminum chloride.....wt pct..	0.1	Fr	4
Armac D 12.....lb/ton..	0.1-0.7	C	14
Cationic surfactant.....wt pct..	0.2-0.7	Fr	4
Dodecylamine acetate.....mol/L..	10 ⁻⁷ -10 ⁻³	C	14
Dodecylammonium chloride.....	NA	Fl	17
Ferric chloride.....wt pct..	0.1	Fr	4
Sodium chloride.....wt pct..	0.1-0.25	Fr	4
Sodium dodecylsulfate.....	NA	Fl	17
Sodium octadecylsulfate.....	NA	Fl	17
Sodium oleate.....	NA	C	14
Sodium silicate.....mg/g..	1.25	C	3
Sulphonic Promoter 801.....lb/ton..	0.3	C	14
XF-4272.....wt pct..	0.02-0.06	C	3
XFS-4272.....lb/ton..	0.5	C	3
LIMESTONE			
Calcium hydroxide.....wt pct..	0.05-0.07	Fr	4
Flotigan P.....wt pct..	0.03	C	3, 16
Sodium carbonate.....wt pct..	0.25	C	6, 10
Sodium hydroxide.....wt pct..	0.05	C	6, 10
Soluble oils.....wt pct..	0.67	Fr	4
MAGNESITE			
Aluminum chloride.....wt pct..	0.1	Fr	4
Cationic surfactant.....wt pct..	0.2-0.7	Fr	4
Ferric chloride.....wt pct..	0.1	Fr	4
Sodium chloride.....wt pct..	0.1-0.25	Fr	4
MARBLE			
Acetone.....	NA	C	3
Benzene.....	NA	C	3
Carbon tetrachloride.....	NA	C	3
Nitromethane.....	NA	C	3

TABLE A-1. - Chemical additives tested for various processing methods--Con.

Additive	Concentrations tested	Method ¹	References ²
QUARTZ			
Acetone.....	Vapor	C	3, 12
Alcohol.....	NA	C	3
Aluminum chloride.....wt pct..	0.02-0.1	C	3, 6
Aluminum nitrate.....eq/L..	10^{-7} - 10^{-1}	Fl	8
Barium nitrate.....eq/L..	10^{-7} - 10^{-1}	Fl	8, 17
Benzene.....	NA	C	3, 12
Carbon tetrachloride.....	NA	C	3
Copper sulfate.....g/L..	1	C	6
Dodecylammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Fl	7, 9, 17
Hydrochloric acid.....mol/L..	0.01	Fl	8
Methyl alcohol.....wt pct..	>10	C	6
MS 66.....wt pct..	1.0	C	6
Nitromethane.....	NA	C	3
Octyl to octadecyl ammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Fl	6
Repelcote.....wt pct..	2.0	C	6
Siliconate D 3032.....wt pct..	1.0	C	6
Sodium chloride.....wt pct..	0.1-0.5	Fl	8, 17
Sodium hydroxide.....mol/L..	10^{-3} - 10^0	Fl	8
Sodium laurate.....eq/L..	10^{-7} - 10^{-1}	Fl	8
Sodium nitrate.....eq/L..	10^{-7} - 10^{-1}	Fl	8
Sodium oleate.....eq/L..	10^{-7} - 10^{-1}	Fl	8
Sodium petroleum sulfonates.....	NA	Fl	1
Water.....	NAP	C	12
Wool grease.....	NA	C	3
QUARTZITE			
Aluminum chloride.....wt pct..	0.02-0.1	Fr	4
Anionic surfactants.....wt pct..	0.4-1.2	Fr	4
Calcium chloride.....wt pct..	0.1-0.2	Fr	4
Flotigan P.....wt pct..	0.03	C	3
Magnesium chloride.....wt pct..	0.1-0.2	Fr	4
Sodium chloride.....wt pct..	0.1-0.5	Fr	4
Soluble oils.....wt pct..	0.5-0.9	Fr	4
RUTILE			
Linoleic acid.....	NA	Fl	17
Linolenic acid.....	NA	Fl	17
Oleic acid.....	NA	Fl	17
Stearic acid.....	NA	Fl	17
SHALE			
Sodium chloride.....wt pct..	0.25-0.5	Fr	4
Soluble oils.....wt pct..	0.17	Fr	4
STEATITE			
Acetone.....	Vapor	C	12
Benzene.....	Vapor	C	12
Water.....	Vapor	C	12
STEEL			
MRS.....	NA	C	13
Ukrinol 14/9.....	NA	C	13
Ukrinol 14/10.....	NA	C	13
URANINITE			
Fe ³⁺ ion (Fe III).....mol..	10^{-4} - 10^{-2}	Fr	18
Sulfate ion.....mol..	10^{-4} - $10^{-1.82}$	Fr	18
ZIRCON			
Triethanolamine.....wt pct..	0.2	C	3

NA Not available. NAP Not applicable.

¹C = comminution or grinding; Fl = flotation; Fr = fragmentation.²Numbers refer to items in the list of references following the table.

REFERENCES A

1. Boulos, T. R., A. G. Yousef, and M. Hilal. Local Petroleum Sulphonate for the Flotation of Some Minerals and Ores. *Tenside*, v. 14, No. 6, Nov.-Dec. 1977, pp. 307-310.
2. Chemical & Engineering News. Chemical Comminution Shows Promise for Coal. V. 52, Sept. 2, 1974, pp. 16-17.
3. Committee on Comminution and Energy Consumption. Comminution and Energy Consumption. Natl. Mater. Advis. Board, Natl. Acad. Sci., Washington, DC, NMAB-364, May 1981, 298 pp.
4. Engelmann, W. H. Chemical Fragmentation. Sec. in SME Mining Engineering Handbook, ed. by A. B. Cummins and I. A. Given. Soc. Min. Eng. AIME, 1973, pp. 11-112 to 11-123.
5. Fattah, W. I. A., T. R. Boulos, A. A. Yousef, and G. N. Gad. The Influence of Additives on the Grinding of γ -Alumina for the Production of High Alumina Ceramics. *Powder Technol.*, v. 3, 1969/1970, pp. 72-77.
6. Frangiskos, A. Z., and H. G. Smith. The Effect of Some Surface Active Reagents on the Comminution of Limestone and Quartz. Paper in Progress in Mineral Dressing (Trans. Int. Miner. Dressing Congr., Stockholm, Sweden, 1957). *Almqvist & Wiksell*, 1958, pp. 67-84.
7. Fuerstenau, D. W., T. W. Healy, and P. Somasundaran. The Role of the Hydrocarbon Chain of Alkyl Collectors in Flotation. *Trans. Soc. Min. Eng. AIME*, v. 229, Dec. 1964, pp. 321-325.
8. Gaudin, A. M., and D. W. Fuerstenau. Quartz Flotation With Anionic Collectors. *Min. Eng. (N.Y.)*, v. 202, Jan. 1955, pp. 66-72.
9. _____. Quartz Flotation With Cationic Collectors. *Min. Eng. (N.Y.)*, v. 202, Oct. 1955, pp. 958-962.
10. Ghosh, S. K., C. C. Harris, and A. Jowette. Beneficial Effects of Reagents in Solution on Wet Crushing of Rock. *Nature (London)*, v. 188, Dec. 31, 1960, p. 1182.
11. Kudryavtseva, N. L., and G. S. Khodakov. (Influence of Surfactant Additives on the Grinding of Clinker.) *Dokl. Akad. Nauk SSSR*, v. 156, No. 2, 1964, pp. 437-440; *Chem. Abstr.*, v. 66, 1967, No. 13831.
12. Locher, F. W., and H. M. von Seebach. Influence of Adsorption on Industrial Grinding. *Ind. and Eng. Chem., Process Des. and Dev.*, v. 11, No. 2, 1972, pp. 190-197.
13. Machine Tools. New Types of Coolant Permit High-Speed Grinding of High-Speed Steels. V. 48, No. 11, 1977, pp. 53-54.
14. Malati, M. A., A. A. Yousef, and M. A. Arafa. The Effect of Flotation Reagents on Grinding. *Powder Technol.*, v. 2, 1968, pp. 21-26.
15. Opoczky, L. (Effect of Surface-Active Agents on Grinding of Cement Clinker.) *Epitoanyag*, v. 21, No. 5, 1969, pp. 188-193; *Chem. Abstr.*, v. 71, 1969, No. 41915m.
16. Somasundaran, P., and I. J. Lin. Effect of the Nature of Environment on Comminution Processes. *Ind. and Eng. Chem., Process Des. and Dev.*, v. 11, No. 3, 1972, pp. 321-331.
17. Sun, S. C., and G. Purcell. The Importance of Electrokinetics in Mineral Flotation. *Miner. Ind. (University Park, PA)*, v. 29, No. 1, Oct. 1959, pp. 1-5.
18. Syracuse University Research Corp. The Effect of Chemical Additives on the Production of Fine Particles in Coal Fragmentation. Final report on BuMines contract H0101704, June 1974, 108 pp.; available upon request from W. H. Engelmann, BuMines, Minneapolis, MN.

APPENDIX B.--SUMMARY OF CHEMICAL ADDITIVES USED IN SURFACE
EFFECTS STUDIES, WITH REFERENCES

TABLE B-1. - Chemical additives tested in measuring various surface effects

Additive	Concentrations tested	Effects ¹	References ²
ALUMINUM CRYSTALS			
Dry air.....	NAp	F	3
Hexadecane.....	NA	F	3
Mercury.....	NA	F	3
ALUMINUM OXIDE			
n-alcohols.....	NA	Z	17-18
Sodium hydroxide.....	NA	Z	17-18
CALCITE			
Benzene.....	NA	S	19
Nitric acid.....	NA	Z	18
Sodium hydroxide.....	NA	Z	18
Water.....	NAp	S	19
CALCIUM FLUORIDE			
Aluminum chloride.....wt pct..	0.0-0.2	R	5
Calcium chloride.....	NA	R	27
DMF.....wt pct..	0-100	R	5, 27
DMSO.....wt pct..	0-100	R	5, 27
DMF in DMSO.....wt pct..	0-50	R	5, 27
n-heptane to n-hexadecane.....wt pct..	Varied	R	5
Silver chloride.....	NA	R	27
Silver nitrate.....	NA	R	27
Sodium chloride.....	NA	R	27
Toluene ³	Pure	R	5, 27
CHRYSSOTILE			
Potassium chloride.....N..	10 ⁻⁵	Z	20
Sodium carbonate plus sodium phosphate mol/L..	10 ⁻²	Z	20
Sodium silicate.....	NA	Z	20
FOSTERITE			
Water.....	NAp	Z	15
GERMANIA			
Fluorobenzene.....	NA	A	23
GLASS			
Aluminum nitrate.....mol/L..	10 ⁻⁸ -10 ⁻²	Z	1
Calcium chloride.....mol/L..	10 ⁻⁴ -10 ⁻²	Z	12
Calcium nitrate.....mol/L..	10 ⁻⁸ -10 ⁻²	Z	1
Crystal violet.....mol/L..	10 ⁻⁸ -10 ⁻²	Z	1
Hydrochloric acid.....wt pct..	Varied	Z	12
Lanthium chloride.....mol/L..	10 ⁻⁴ -10 ⁻²	Z	12
n-alcohols (methanol to dodecyl).....	NA	F, Z	16, 18, 29
Potassium chloride.....mol/L..	10 ⁻⁸ -10 ⁻²	Z	1
Sodium chloride.....mol/L..	10 ⁻⁴ -10 ⁻²	Z	12
Sodium dodecyl sulfate.....	NA	S	22
Sodium tetradecyl sulfate.....	NA	S	22
Synovial fluid.....	NA	S	22
Tetradecyldimethyl ammonium bomide.....	NA	S	22
Thorium nitrate.....mol/L..	10 ⁻⁸ -10 ⁻²	Z	1
Toluene.....	NA	Z	18

See notes at end of table.

TABLE B-1. - Chemical additives tested in measuring various surface effects--Con.

Additive	Concentrations tested	Effects ¹	References ²
GRANITE			
Aluminum chloride.....mol/L..	3×10^{-6} - 1×10^{-4}	Z	6
DTAB.....mol..	10^{-3}	Z	18
n-alcohols.....	NA	Z	18
Oleylammonium acetate.....	NA	Z	6
Toluene.....	NA	Z	18
LIMESTONE			
Aniline.....	NA	R	11
Benzaldehyde.....	NA	R	11
Benzene.....	NA	R	11
Ethyl alcohol.....	NA	R	11
Ethylene glycol.....	NA	R	11
Glycerine.....	NA	R	11
n-butyl alcohol.....	NA	R	11
Nitrobenzene.....	NA	R	11
1,3-dibromopropane.....	NA	R	11
Toluene.....	NA	R	11
LITHIUM FLUORIDE			
Aluminum chloride... ..wt pct..	0.1	R	5
Caprylic to stearic acids.....N..	10^{-6} - 10^{-2}	R	26
DMF.....wt pct..	0-100	R; Z	5; 17
DMSO.....wt pct..	0-100	R	5
DMF in DMSO.....wt pct..	0-50	R	5
Hexadecane.....	NA	F	4
Hexadecane with organic acids.....	NA	F	4
Oleic acid.....	NA	F	4
Toluene.....	NA	R; Z	5; 17
Water.....	NAP	R; Z	5; 17
MAGNESIUM OXIDE			
Aluminum chloride.....wt pct..	0.1	R	5
DMF.....wt pct..	0-100	F; R; Z	16; 5, 28; 18
DMSO.....wt pct..	0-100	F; R; Z	16; 5, 28; 18
DMF in DMSO.....wt pct..	0-50	F; R	16; 5, 28
n-heptane to n-hexadecane.....wt pct..	Varied	F; R	16; 5
Sodium chloride.....N..	10^{-2}	F; Z	16; 17
Toluene.....	NA	Z	18
Water.....	NAP	F	16
QUARTZ			
Aluminum chloride.....wt pct..	0.02-0.1	F	25
Ammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Z	8
Calcium chloride.....mol..	10^{-4} - 10^{-2}	Z	12
Cetyltrimethyl ammonium bromide.....	NA	S	30
Decylammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Z	8
Dodecylammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Z	7-8
Dodecylammonium acetate plus sodium carbonates.....mol/L..	10^{-4} - 6×10^{-5} 1.6×10^{-4} - 10^{-3}	Z	8
DTAB.....	NA	Z	18
Hexadecylammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Z	8
Hydrochloric acid.....mol/L..	0.1	Z	12
Lanthium chloride.....mol..	10^{-4} - 10^{-2}	Z	12

TABLE B-1. - Chemical additives tested in measuring various surface effects--Con.

Additive	Concentrations tested	Effects ¹	References ²
QUARTZ--Continued			
n-alcohols.....	NA	Z	18
Octylammonium acetate.....mol/L..	10 ⁻⁷ -10 ⁻¹	F; Z	25; 8
Potassium chloride.....	NA	Z	18
Potassium iodide in isopropyl alcohol.....	NA	Z	18
Sodium chloride.....wt pct..	0.1-0.5	S; Z	30; 12
Do.....mol/L..	10 ⁻⁴ -10 ⁻³		
Sodium dodecyl sulfate.....	NA	S	30
Tetradecylammonium acetate.....mol/L..	10 ⁻⁷ -10 ⁻¹	Z	8
Thorium nitrate.....	NA	Z	18
SILICA			
Acetone.....	NA	A	9
Benzene.....	NA	A	9
Calcium chloride.....mol..	10 ⁻⁴ -10 ⁻²	Z	12
CTAB.....	NA	A	2
Diethyl ether.....	NA	A	9
DTAB.....	NA	A	2
Hexane.....	NA	A	9
Hydrochloric acid.....wt pct..	Varied	Z	12
Lanthium chloride.....mol..	10 ⁻⁴ -10 ⁻²	Z	12
Methanol.....	NA	A	9
Pyridene.....	NA	A	9
Sodium chloride.....mol..	10 ⁻⁴ -10 ⁻²	Z	12
Triethylamine.....	NA	A	9
Water.....	NAP	A	9
STEEL			
Benzene.....	NA	R	13
Carbon tetrachloride.....	NA	S	24
Molybdenum sulfate.....	NA	F	10
Oleic acid.....	NA	R	13
Stearic acid.....wt pct..	0.1	A	14
Tungsten sulfate.....	NA	F	10
TIN			
Allyl alcohol.....	NA	A	14
Dodecyl alcohol.....	NA	A	14
Lauryl chloride.....	NA	A	14
Methyl laurate.....	NA	A	14
n-propyl alcohol.....	NA	A	14
Octylamine.....	NA	A	14
Oleic acid.....	NA	A	21
Paraffin.....wt pct..	0.2	A	21
Saturated fatty alcohols.....	NA	A	14
ZINC CRYSTALS			
Oleic acid.....wt pct..	0.1	A	21
Paraffin.....wt pct..	0.2	A	21

NA Not available. NAP Not applicable.

¹A = adsorption; F = friction and wear; R = Rebinder effect; S = surface effects; Z = zeta potential.²Numbers refer to items in the list of references following the table.³<0.02 pct water.

REFERENCES B

1. Akers, R. J. Zeta Potential and the Use of the Electrophoretic Mass Transport Analyzer. *Am. Lab.* (Fairfield, CT), v. 4, June 1972, pp. 41-53.
2. Bijsterbosch, B. H. Characterizations of Silica Surfaces by Adsorption From Solution. Investigations Into the Mechanism of Adsorption of Cationic Surfactants. *J. Colloid and Interface Sci.*, v. 42, No. 1, Apr. 1974, pp. 186-189.
3. Buckley, D. H. Effect of Orientation and the Presence of Surface-Active Materials on the Friction, Deformation, and Wear of Aluminum. NASA Tech. Note, NASA-TN-D-4994, 1969, 22 pp.; *Chem. Abstr.*, v. 70, 1969, No. 60244n.
4. _____. Influence of Surface-Active Agents on Friction, Deformation, and Fracture of Lithium Fluoride. NASA Tech. Note, NASA-TN-D-4716, 1968, 26 pp.; *Chem. Abstr.*, v. 69, 1968, No. 62302h.
5. Ceramic Awareness Bulletin. Re-binder Effects in Ceramics. No. 23, July-Aug. 1970, pp. 20-25.
6. Engelmann, W. H., O. Terichow, and A. A. Selim. Zeta Potential and Pendulum Schlerometer Studies of Granite in a Solution Environment. BuMines RI 7048, 1967, 16 pp.
7. Fuerstenau, D. W. Correlation of Contact Angles, Adsorption Density, Zeta Potentials and Flotation Rate. *Min. Eng.* (N.Y.), v. 9, No. 12, Dec. 1957, pp. 1365-1367.
8. _____. Streaming Potential Studies on Quartz in Solutions of Aminium Acetates in Relation to the Formation of Hemi-micelles at the Quartz-Solution Interface. *J. Phys. Chem.*, v. 60, July 1956, pp. 981-985.
9. Hair, M. L., and W. Hertil. Adsorption on Hydroxylated Silica Surfaces. *J. Phys. Chem.*, v. 73, Dec. 1969, pp. 4269-4276.
10. Has, Z. (Rebinder Effect and Coefficient of Friction During Metal Working Processes.) *Zesz. Nauk.-Politech. Lodz. Mech.*, v. 25, 1968, pp. 5-72; *Chem. Abstr.*, v. 72, 1970, No. 82238g.
11. Heins, R. W. Studies of the Rebinder Effect by the Rebinder-Kuznetsov Pendulum. Ph. D. Thesis, Univ. IL, Urbana, IL, 1964, 111 pp.
12. Jednacek, J., V. Pravdic, and W. Haller. The Electrokinetic Potential of Glasses in Aqueous Electrolytic Solutions. *J. Colloid and Interface Sci.*, v. 49, No. 1, Oct. 1974, pp. 76-23.
13. Karpenko, G. V., E. M. Gutman, and I. I. Vasilenko. (The Binder Effect in Corrosive and Weak Surface-Active Media.) *Fiz.-Khim. Mekh. Mater.*, v. 3, 1967, pp. 523-532; *Chem. Abstr.*, v. 68, 1968, No. 71530m.
14. Katsov, K. B. (Adsorption Lowering of the Contact Durability of ShKh15 Steel.) *Fiz.-Khim. Mekh. Mater.*, v. 4, 1968, pp. 432-434; *Chem. Abstr.*, v. 70, 1969, No. 22168h.
15. Luce, R. W., and G. A. Porks. Point of Zero Charge of Weathered Forsterite. *Chem. Geol.*, v. 12, 1973, pp. 147-153.
16. Macmillan, N. H., R. D. Huntington, and A. R. C. Westwood. Chemomechanical Control of Sliding Friction Behavior in Nonmetals. Martin Marietta Corp., Baltimore, MD, MML Tech. Rep. 73-16c, Nov. 1973, 39 pp.
17. _____. Relationship Between Zeta Potential and Dislocation Mobility. Martin Marietta Corp., Baltimore, MD, MML Tech. Rep. 73-11c, July 1973, 26 pp.
18. Macmillan, N. H., and A. R. C. Westwood. Surface Charge-Dependent Mechanical Behavior of Non-Metals. Martin Marietta Corp., Baltimore, MD, MML Tech. Rep. 73-13c, Sept. 1973, 43 pp.
19. Mardles, E. W., Jr. Annual Conference of the British Society of Rheology. *Nature* (London), v. 176, Oct. 29, 1955, pp. 819-820.
20. Martinez, E., and G. L. Zucker. Asbestos Ore Body Minerals Studied by Zeta Potential Measurements. *J. Phys. Chem.*, v. 64, July 1960, pp. 924-926.
21. Rebinder, P. A., V. I. Likhtman, and V. M. Maslennikov. (Deformation of Single Crystals of Metals as Facilitated by Adsorption of Surface-Active Substances.) *C. R. Acad. Sci. URSS*, v. 32, 1941, pp. 125-129; *Chem. Abstr.*, v. 37, 1943, No. 812.
22. Roberts, A. D. Direct Measurement of Electrical Double-Layer Forces Between

Solid Surfaces. J. Colloid and Interface Sci., v. 41, No. 1, Oct. 1972, pp. 23-34.

23. Sahay, B. K., and M. J. D. Law. Interactions Between Surface Hydroxyl Groups and Adsorbed Molecules. V. Fluorobenzene Adsorption on Germania. J. Colloid and Interface Sci., v. 48., No. 1, July 1974, pp. 20-31.

24. Shirakashi, T., R. Komanduri, and M. C. Shaw. The Conflicting Roles of Carbontetrachloride as a Boundary Lubricant. J. Eng. Ind., v. 100, No. 2, May 1978, pp. 244-248.

25. Tweeton, D. R. Effect of Environment on Friction and Wear Between Quartz and Steel. BuMines RI 8124, 1976, 25 pp.

26. Westwood, A. R. C. The Rebinder Effect and the Adsorption-Locking of Dislocations in Lithium Fluoride. Res. Inst. Adv. Studies, Baltimore, MD, Tech. Rep. WAL-TR. 832/1-3, 1961, 36 pp.

27. Westwood, A. R. C., J. S. Ahern, and J. J. Mills. Developments in the Theory and Application of Chemomechanical Effects. Colloids and Surf., v. 2, 1981, pp. 1-35.

28. Westwood, A. R. C., and D. L. Goldheim. Occurrence and Mechanism of Rebinder Effects in CaF_2 . J. Appl. Phys., v. 39, No. 7, July 1968, pp. 3401-3405.

29. Westwood, A. R. C., C. M. Preece, and D. L. Goldheim. Adsorption-Sensitive Mechanical Behavior. Ch. in Molecular Processes on Solid Surfaces, ed. by E. Drauglis (3d Battelle Inst. Mater. Sci. Colloq.). McGraw-Hill, 1969, pp. 591-610; Chem. Abstr., v. 71, 1969, No. 116868j.

30. Yopps, J. A. The Zero Point of Charge of Alumina in Aqueous Systems. M.S. Thesis, Univ., CA, Berkeley, CA, 1963, 39 pp.

APPENDIX C.--SUMMARY OF CHEMICAL ADDITIVES USED TO STUDY
VARIOUS MECHANICAL PROPERTIES, WITH REFERENCES

TABLE C-1. - Chemical additives tested for measuring various mechanical properties

Additive	Concentrations tested	Properties ¹	References ²
ALUMINA			
n-alcohols.....	NA	F	24
Toluene.....	NA	F	24
Water.....	NAp	F	24
ALUMINUM CRYSTALS			
Distilled water.....	NAp	F	4
Dry air.....	NAp	F	4
Methanol.....	NA	F	4
Organic liquids.....wt pct..	0-100	H	15
Sea water.....	NAp	F	4
Stearic acid.....mol/L..	0.0-2.1	M	9
ALUMINUM OXIDE			
Toluene.....	NA	H	23
CADMIUM CRYSTALS			
Oleic acid.....mol/L..	0.1-2.1	M	9
CALCITE			
Butyl alcohol ³	Pure	F	24
Colophonium.....	NA	H	8
Fatty alcohols.....	NA	S	13
n-butyric acid.....	NA	H	8
n-propyl alcohol.....	NA	H	8
Oleic acid in Toluol.....	NA	H	8
Oleic acid in vaseline oil.....	NA	H	8
Phenol in benzene.....	NA	H	7
Polar liquid.....	Pure	H	7-8
CALCIUM FLUORIDE			
Air.....	NAp	H	17
DMF.....wt pct..	0-100	F; H; M	21, 24; 23; 22
DMSO.....wt pct..	0-100	H; M	23; 22
DMF in DMSO.....wt pct..	0-50	H	23
Isooctane.....	NA	H	23
n-heptane to n-hexadecane.....	NA	F	21
Nitrogen.....	NAp	H	17
Oxygen.....	NAp	H	17
Toluene.....	NA	F; H	21; 23
Water.....	NAp	H	23
CEMENT-CLINKER			
Naphthalene sulphonic acid.....	NA	M	12
COPPER			
Toluene.....	NA	H	23
GERMANIA			
Toluene.....	NA	H	23
GLASS			
Acetone.....	NA	F; H	24; 23
Aluminum chloride.....N..	10 ⁻³ -10 ⁻²	S	20
Dodecylammonium chloride.....N..	10 ⁻⁵ -10 ⁻²	S	20
Fatty alcohols.....	NA	S	13
Iso-amyl alcohol.....wt pct..	2.5	H	23
n-alcohols.....wt pct..	Varied	F; H	24; 23
n-alkanes.....	NA	H	23
Potassium chloride.....	NA	H	23
Sodium carbonate.....wt pct..	10 ⁻⁵	S	20
Sodium dioctyl sulfonsuccinate.....wt pct..	0.5	H; S	23; 13
Stearamidomethyl pyridinium chloride.....	NA	S	20

See notes at end of table.

TABLE C-1. - Chemical additives tested for measuring various mechanical properties--Con.

Additive	Concentrations tested	Properties ¹	References ²
GLASS--Continued			
Thorium nitrate.....	NA	H	23
Toluene.....	NA	F; H	24; 23
Velan.....wt pct..	0.5	H	23
Water.....	NAp	F; H; S	24; 23; 20
GOLD			
Oleic acid.....	NA	M	12
GRANITE			
DTAB.....mol/L..	10 ⁻⁴	F; H	24, 11; 23
n-alcohols.....	NA	F; H	24; 23
Toluene.....	NA	F	24
Water.....	NAp	F	24
GRAPHITE ORES			
Acetic acid.....	NA	H	3
LIMESTONE			
α-hydroxyladipaldehyde.....	NA	H	14
α-nitro β-naphthol.....	NA	H	14
Aniline.....	NA	H	6
Armac CD-50.....	NA	H	14
Benzaldehyde.....	NA	H	6
Benzene.....	NA	H	6
Benzyl dimethylamine.....	NA	H	14
Calcium chloride.....	NA	H	14
Detergent RAS.....wt pct..	0.25	M	18
DMS.....	NA	H	14
Ethyl alcohol.....	NA	H	6
Ethylene diamine.....	NA	H	14
Ethylene glycol.....	NA	H	6
Glycerine.....	NA	H	6
Mine water.....	NAp	M	18
MRYJ 52.....	NA	H	14
n-butyl alcohol.....	NA	H	6
n-hexadecane.....	NA	S	1
Nitrobenzene.....	NA	H	6
Oleic acid.....	NA	S	1
Nonpolar kerosine.....	Pure	M	18
l-leucine.....	NA	H	14
1,3-dibromopropane.....	NA	H	6
Saturated calcium chloride.....	NA	S	1
Sodium adipate.....	NA	H	14
Sodium azelate.....	NA	H	14
Sodium carbonate.....wt pct..	0.25	M	18
Sodium citrate.....	NA	H	14
Sodium glutarate.....	NA	H	14
Sodium mercaptosuccinate.....	NA	H	14
Sodium oleate.....	NA	H	14
Sodium oxalate.....	NA	H	14
Sodium picrate.....	NA	H	14
Sodium salts of dicarboxylic acid.....	NA	H	14
Sodium thioxanates.....	NA	H	14
Stearic acid.....wt pct..	0.1	M	18
Toluene.....	NA	H	6
WR 2472.....	NA	H	14
LITHIUM FLUORIDE			
DMF.....wt pct..	0-100	F	21
Heptane.....	NA	F	21
Hexadecane.....	NA	F	21

TABLE C-1. - Chemical additives tested for measuring various mechanical properties--Con.

Additive	Concentrations tested	Properties ¹	References ²
LITHIUM FLUORIDE--Continued			
Myristic acid.....	NA	H	23
Toluene ⁴	Pure	F; H	21; 23
Water.....	Nap	F	21
MAGNESIUM OXIDE			
DMF.....wt pct..	0-100	F; H; M	21, 24; 23; 22
DMSO.....wt pct..	0-100	H; M	23; 22
DMF in DMSO.....wt pct..	0-50	H	23
n-alcohols.....	NA	H	23
n-heptane to n-hexadecane.....	NA	F	21
Toluene ⁴	Pure	F; H	21; 23
Water.....	Nap	H	23
MARBLE			
Detergent RAS.....wt pct..	0.25	M	18
Mine water.....	Nap	M	18
Nonpolar kerosine.....	Pure	M	18
Sodium carbonate.....wt pct..	0.25	M	18
Stearic acid.....wt pct..	0.1	M	18
MICA			
Fatty alcohols.....	NA	S	13
NICKEL (Ni-Al)			
Toluene.....	NA	H	23
POTASSIUM BROMIDE			
Toluene.....	NA	H	23
QUARTZ			
Aluminum nitrate.....mol/L..	10^{-7} - 10^{-2}	F; H	24; 23
Ammonia.....	NA	M	16
DTAB.....mol/L..	2.5×10^{-5} - 10^{-3}	F	24
Phosphoric acid.....	NA	M	16
Sulfuric acid.....	NA	M	16
QUARTZITE			
Aluminum chloride.....wt pct..	0.02-0.1	S	19
Naphthenic oil with sodium carbonate.....wt pct..	0.2-5		
	0.25	S	19
Sodium chloride.....wt pct..	0.1-0.5	S	19
SANDSTONE			
Aluminum chloride.....wt pct..	0.02-0.1	S	20
Distilled water.....	Nap	S	1, 20
Dodecylammonium chloride.....N..	10^{-5} - 10^{-2}	S	20
DTAB.....	NA	F	10
n-hexadecane.....	NA	S	1
Oleic acid.....	NA	S	1
Oleylamine.....	NA	S	1
Sodium azelate.....wt pct..	2.0	H	14
Sodium carbonate.....wt pct..	0.25	S	20
Sodium dodecyl sulfate.....	NA	F	10
Triton x-100.....	NA	F	10
SILICA			
Acetone.....	Vapor	F	5
Benzene.....	Vapor	F	5
Ethyl acetate.....	Vapor	F	5
Ethyl alcohol.....	Vapor	F	5
n-butyl alcohol.....	Vapor	F	5
n-propyl alcohol.....	Vapor	F	5
Water.....	Nap	F	5

See notes at end of table.

TABLE C-1. - Chemical additives tested for measuring various mechanical properties--Con.

Additive	Concentrations tested	Properties ¹	References ²
STEEL			
Acetic anhydride.....	NA	H	15
Acetone.....	NA	M	2
Acetone with dioctyl sebecate.....	NA	M	2
Alcohols.....	NA	M	2
Butyl lithium.....	NA	H	15
Caprylic acid.....	NA	H	15
Carbolic acid.....	NA	H	15
Carbon tetrachloride.....	NA	H	15
Chloroform.....	NA	H	15
dibutyl mercury.....	NA	H	15
diethyl mercury.....	NA	H	15
Dioxane.....	NA	H	15
Hexane.....	NA	M	2
Iso-octane.....	NA	M	2
Light mineral oil.....	NA	H	15
Methyl chloride.....	NA	H	15
Mineral oils.....	NA	M	2
Myristic acid.....	NA	H	15
Oil 12 with stearic acid.....wt pct..	0.1	H	15
Palmitic acid.....	NA	H	15
Paraffinic acids.....	NA	M	2
Propionic acid.....	NA	H	15
Propyl chloride.....	NA	H	15
Tetra-n-butyl tin.....	NA	H	15
TIN			
Acetone.....	NA	M	2
Acetone with dioctyl silicate.....	NA	M	2
Alcohols.....	NA	M	2
Allyl alcohol.....	NA	S	13
Caprylic acid.....	NA	M	9
Dodecyl alcohol.....	NA	S	13
Hexane.....	NA	M	2
Iso-octane.....	NA	M	2
Lauryl chloride.....	NA	S	13
Methyl laurate.....	NA	S	13
Mineral oils.....	NA	M	2
n-propyl alcohol.....	NA	S	13
Octylamine.....	NA	S	13
Oleic acid.....	NA	M	9
Paraffinic acids.....	NA	M	2
Propionic acid.....	NA	M	9
Saturated fatty alcohols.....	NA	S	13
Sodium dioctyl sulfosuccinate.....	NA	S	13
Stearic acid.....	NA	M	9
Toluene.....	NA	H	23
TITANIUM CARBIDE			
Toluene.....	NA	H	23
ZINC CRYSTALS			
Oleic acid.....wt pct..	0.1	M	9

NA Not available. NAP Not applicable.

¹F = fracture and crack propagation; H = hardness; M = mechanical properties; S = strength of materials.²Numbers refer to items in the list of references following the table.³10 pct water.⁴<0.02 pct water.

REFERENCES C

1. Boozer, G. D., K. H. Heller, and S. Serdengecti. Effects of Pore Fluids on the Deformation Behavior of Rocks Subjected to Triaxial Compression. Ch. in *Rock Mechanics*, ed. by C. Fairhurst. Pergamon, 1963, pp. 579-625.
2. Fuks, G. I., S. G. Uskova, I. B. Gantsevich, and Z. A. Kuteinikova. (Effect of the Composition of a Medium of Low Polarity and of the Solutions of Surfactants on the Mechanical Properties of the Surface Layer of Solids.) *Kolloid. Zh.*, v. 35, No. 5, 1973, pp. 854-859; *Chem. Abstr.*, v. 79, 1973, No. 149759t.
3. Gilman, J. J. Theory of Solution Strengthening of Alkali Halide Crystals. *J. Appl. Phys.*, v. 45, No. 2, Feb. 1974, pp. 508-509.
4. Grosskreutz, J. C. The Effect of Environment on the Fracture of Adhering Aluminum Oxide. *J. Electrochem. Soc.*, v. 117, No. 7, July 1970, pp. 940-943.
5. Hammond, M. L., and S. F. Ravitz. Influence of Environment on Brittle Fracture of Silica. *J. Am. Ceram. Soc.*, v. 46, No. 7, July 1963, pp. 329-332.
6. Heins, R. W., and N. Street. Hardness Reduction Through Wetting. *Trans. Soc. Min. Eng. AIME*, v. 229, June 1964, pp. 223-224.
7. Hiller, K. H. Reduction of Free Surface Energy of Solid Crystals Through Wetting by Organic Solutions as Determined by Hardness Measurements. *Pres. at ACS Meet.*, Boston, MA, Apr. 5, 1959, 1 p.; available upon request from W. H. Engelmann, BuMines, Minneapolis, MN.
8. _____. Reduction of Hardness of Calcite by Adsorption at the Solid-Liquid Interface. *Pres. at ACS Meet.*, Chicago, IL, Sept. 7, 1958, 1 p.; available upon request from W. H. Engelmann, BuMines, Minneapolis, MN.
9. Kramer, I. R. The Effect of Surface Active Agents on the Mechanical Behavior of Aluminum Single Crystals. *Trans. Metall. Soc. AIME*, v. 221, Oct. 1961, pp. 989-993.
10. Lewis, L. W., and D. E. Dunn. Effect of Aqueous Surfactants on Crack Propagation in Orthoquartzite. *Geol. Soc. America Abstr.*, 1976, p. 978.
11. Mills, J. J., R. D. Huntington, and A. R. C. Westwood. Environment-Sensitive Wedge Indentation Behavior of Granites. *Int. J. Rock Mech., Min. Sci., and Geomech. Abstr.*, v. 13, 1976, pp. 289-290.
12. Petrie, E. M. Effect of Surfactant on the Viscosity of Portland Cement Water Dispersions. *Ind. and Eng. Chem., Prod. Res. and Dev.*, v. 15, No. 4, Dec. 1976, pp. 242-249.
13. Rebinder, F., and V. Lichtman. (Effect of Surface Active Media on Strains and Ruptures in Solids.) Paper in *Proceedings of the 2d International Congress of Surface Activity*. Academic, v. 3, 1957, pp. 563-582; available upon request from W. H. Engelmann, BuMines, Minneapolis, MN.
14. Robinson, L. H. Effect of Hardness Reducers on Failure Characteristics of Rock. *Soc. Pet. Eng. J.*, v. 7, 1963, pp. 295-300.
15. Rostoker, W. Embrittlement of Metals by Organic Liquids. *IIT Res. Inst.*, Rep. ARF-B183-14, May 31, 1963, 16 pp.; Rep. IIT RI-B183-B2-5, May 31, 1964, 11 pp.
16. Ruff, O., and B. Hirsch. (Plastic Materials From Silica.) *Z. Anorg. und Allg. Chem.*, v. 173, 1928, pp. 14-26; *Chem. Abstr.*, v. 22, 1928, No. 4031.
17. Sashital, S. R., and K. Vedam. Hardening of CaF_2 Single-Crystal Surfaces Due to Contamination by Atmospheric Oxygen. *J. Appl. Phys.*, v. 43, No. 11, Nov. 1972, pp. 4396-4400.
18. Shreiner, L. A. (Effects of Liquid Environment on Mechanical Properties of Rocks.) *Minneapolis Transl.* No. 293, 1958, pp. 89-97; available upon request from W. H. Engelmann, BuMines, Minneapolis, MN.
19. Vutukuri, V. S. Effect of Aluminum Chloride Solutions on the Tensile Strength of Quartzite. *Trans. Soc. Min. Eng. AIME*, v. 252, Dec. 1972, pp. 407-409.

20. Wang, F. D. The Strength Alteration of Rocks and Glass in Liquid Environments. Ph. D. Thesis, Univ. IL, Urbana, IL, 1966, 83 pp.

21. Westwood, A. R. C., R. D. Huntington, and N. H. Macmillan. Influence of Environment on the Mobility of Near-Surface Dislocations in Ionic Crystals. J. Appl. Phys., v. 44, No. 11, Nov. 1973, pp. 5194-5195.

22. Westwood, A. R. C., and R. M. Latanision. Environment-Sensitive Machining Behavior of Nonmetals. NBS Spec. Publ. 348, May 1972, pp. 141-154.

23. Westwood, A. R. C., and N. H. Macmillan. Environment-Sensitive Hardness of Non-Metals. Res. Inst. Adv. Studies, Baltimore, MD, Tech. Rep. 72-08c, RIAS 5th Tech. Rep. to U.S. Off. Nav. Res., Apr. 1972, 76 pp.

24. Westwood, A. R. C., and J. J. Mills. Application of Chemomechanical Effects to Fracture-Dependent Industrial Processes. Martin Marietta Corp., Baltimore, MD, MML Tech. Rep. 75-39c, Oct. 1975, 28 pp.

APPENDIX D.--GENERAL DRILLING BIBLIOGRAPHY

Armour Research Foundation (IIT Res. Inst.). Dislocation Mobility and Pinning in Hard Materials Through Internal Friction Studies. Tech. Doc. Rep., NR ASD-TDR-62-431, pt. 2, June 1963, 95 pp.

Azimov, P. K., Zh. A. Akilov, Sh. Sh. Shaishkhakov, S. Z. Makhmudov, T. M. Makhmudov, and N. M. Mamadzhannov. (Treating a Drilling Mud by Introducing an Additive.) U.S.S.R. Pat. 543,662, Jan. 25, 1977; Chem. Abstr., v. 87, 1977, No. 204110s.

Beckman, R. T. Use of Hardness Reducers in Drilling. CO Sch. Mines, Golden, CO, Min. Dep., Min. 507, Nov. 20, 1961, 7 pp.

Benson, R. E., and J. E. Castle. Reactions of Freshly Formed Surfaces of Silica. J. Phys. Chem., v. 62, July 1958, pp. 840-843.

Beyer, G. (Influence of Surface-Active Additives to Flushing Liquid on the Drilling Speed in the Case of Percussive Drilling.) Rudy, v. 15, No. 8, 1967, pp. 219-224; Chem. Abstr., v. 68, 1968, No. 51520f.

Bruce, W. E. Bureau of Mines Conducts Diamond Drilling Experiments. Mines Mag., v. 58, No. 4, Apr. 1968, pp. 17-21.

Bruce, W. E., and J. Paone. Energetics of Percussive Drills. BuMines RI 7253, 1969, 31 pp.

Burke, J. J., N. L. Reed, and V. Weiss (eds.). Surfaces and Interfaces II. Physical and Mechanical Properties (Proc. 14th Sagamore Army Mater. Res. Conf., Raquette Lake, NY, Aug. 22-25, 1967). Syracuse Univ. Press, 1968, 498 pp.

Chemical and Engineering News. New Figures Show Large Electroviscous Effects. V. 54, June 27, 1966, pp. 46-47.

Chwala, A., and W. Anger. Surfactants. Endeavour, v. 30, No. 110, May 1971, pp. 97-100.

Coghill, W. H., and C. O. Anderson. Certain Interfacial Tension Equilibria Important in Flotation. BuMines TPY 262, 1923, 55 pp.

Corwine, J. W. Measurement of the Surface Energy of Rock by the Three-Point Bending of Notched Beams. M.S. Thesis, Univ. MO-Rolla, 1970, 43 pp.

DeChiffre, L. Testing the Overall Performance of Cutting Fluids. Lubr. Eng., v. 34, No. 5, May 1978, pp. 244-251.

Drozd, M. S., and A. V. Drozdov. (A Method for Measuring the Hardness of Specimens With a Rough Surface.) Zavod. Lab., v. 29, No. 12, Dec. 1963, pp. 1485-1488.

Engineering and Mining Journal. Firing Bullets To Crack Rock for Blasthole Drilling. V. 183, No. 12, Dec. 1982, p. 29.

Epshtein, E. F., L. V. Korchagin, N. A. Dudlya, and N. M. Gavrilenko. (Use of Surface-Active Substances To Increase the Drilling Rate.) Izv. Vyssh. Uchebn. Zaved., Geol. i Razved., v. 12, No. 12, pp. 143-146; Chem. Abstr., v. 72, 1970, No. 91670u.

Eronini, I. E., W. H. Somerton, and D. M. Auslander. Dynamic Model for Rotary Rock Drilling. J. Energy Resour. Technol., v. 104, No. 2, June 1982, pp. 108-120.

Floreen, S., E. E. Mucke, and D. V. Razon. A Review of the Effects of Environment on the Mechanical Properties in Solids. Dep. Chem. and Metall. Eng., Univ. MI, Ann Arbor, MI, June 10, 1960, 48 pp.

Fox, P. G. Review - Mechanically Initiated Chemical Reactions in Solids. J. Mater. Sci., v. 10, 1975, pp. 340-360.

Fuerstenau, D. W. Measuring Zeta Potential by Streaming Potential Techniques. Min. Eng. (N.Y.), v. 10, No. 8, Aug. 1958, pp. 834-835.

Gaudin, A. M. Comminution as a Chemical Reaction. Min. Eng. (N.Y.), v. 7, No. 6, June 1955, pp. 561-562.

Gaudin, A. M., and J. G. Morrow. Adsorption of Dodecylammonium Acetate on Hematite and Its Flotation Effect. Trans. Soc. Min. Eng. AIME, v. 199, Dec. 1954, pp. 1196-1202.

Gideon, D. R. Simon, and H. Grover. Drill Faster and Deeper. Oil & Gas J., v. 54, No. 42, Feb. 20, 1965, pp. 143-144.

Gilbert, B. W. Shore Scleroscope Hardness Tests Made on Moh's Scale Minerals

From Talc to Quartz, Inclusive. Pres. at AIME Annu. Meet., Los Angeles, CA, Feb. 16-19, 1953, 28 pp.; available upon request from W. H. Engelmann, BuMines, Minneapolis, MN.

Gilson, J. R., and R. J. Schallenkamp. Clear-Water Drilling Fluid. U.S. Pat. 3,338,320, Aug. 29, 1967; Chem. Abstr., v. 67, 1967, No. 92543p.

Grant, W. H. Abrasion pH, An Index of Chemical Weathering. Clays and Clay Miner., v. 17, 1969, pp. 151-155.

Grosskreutz, J. C., and C. Q. Bowles. A Study of the Effect of Surface Films on Fatigue Fracture. U.S. Dep. Commerce, Off. Tech. Serv., Rep. AD 605851, 1964, 40 pp.

Hair, M. L., and A. M. Filbert. Surface Chemistry of Glass. Res./Dev., v. 21, Oct. 1969, pp. 34-38.

Halasyamani, R., V. Venkatachalam, and R. Mallikarjunan. Influence of pH on the Kinetics of Comminution of Quartz. Ind. and Eng. Chem., Process Des. and Dev., v. 7, No. 1, Jan. 1968, pp. 79-83.

Hamlin, D. Electrophoresis To Reduce the Drag on the Plow. U.S. Natl. Sci. Found., Undergrad. Res. Proj. Rep., Univ. AZ, Tucson, AZ, summer 1977, 16 pp.

Hartley, J. N., K. A. Presbey, and O. J. Wick. Chemical Additives for Ore Grinding: How Effective Are They? Eng. and Min. J., v. 179, No. 10, Oct. 1978, pp. 105-111.

Hille, M. (High Temperature Resistant Water Based Drilling Fluids.) Erdgas-Z., v. 97, No. 10, Oct. 1981, pp. 371-374.

Hoenig, S. A. Application of Electrical Technology To Monitor the Ball Milling Process and Reduce the Rate of Wear of the Grinding Media. Min. Eng. (N.Y.), v. 36, No. 1, Jan. 1984, pp. 75-76.

Hoyt, J. W. The Effect of Additives on Fluid Friction. J. Basic Eng., v. 94, June 1972, pp. 258-285.

Hustrulid, W. A. The Percussive Drilling of Quartzite. J. S. Afr. Inst. Min. & Metal., v. 71, July 1971, pp. 245-268.

Jaycock, M. J. Properties of the Solid-Liquid Interface of Relevance to Dispersion. Ch. in Dispersion of Powders in Liquids, ed. by G. D. Parfitt.

Applied Science Publ., 1981, pp. 51-98.

Kagarmanov, N. F., A. N. Mikhailov, M. G. Davletbaev, and S. P. Rasskazova. (Effect of Surfactants on the Wettability of Diamond Surfaces.) Tr., Bashk. Gos. Nauchno-Issled. Proektn. Inst. Neft. Promsti., v. 48, 1976, pp. 3-6; Chem. Abstr., v. 88, 1978, No. 155363m.

Karpenko, G. V. (Rebinder Effect and the Strength of Polycrystalline Metals.) Vopr. Fiz.-Khim. Mekh. Mater., 1968, pp. 3-4; Chem. Abstr., v. 72, 1970, No. 124517e.

Karpenko, G. V., I. I. Vasilenko, M. G. Khitarishvili, and V. S. Fedchenko. (Rebinder Effect in a Hydrogen Medium.) Dokl. Akad. Nauk SSSR, v. 185, No. 5, 1969, pp. 1034-1036; Chem. Abstr., v. 71, 1969, No. 23999n.

Kharchenko, L. S., M. Sh. Kendis, A. N. Yarov, and Yu. T. Gordash. (Antiwear and Antifriction Additives to Drilling Fluids During the Drilling of Deep Wells.) Neftepererab. i Neftekhim., No. 8, 1972, pp. 50-53; Chem. Abstr., v. 79, 1973, No. 94260r.

Klimpel, R. R., and L. G. Austin. Chemical Additives for Wet Grinding of Minerals. Powder Technol., v. 31, 1982, pp. 239-253.

Kozubovskii, A. I., B. V. Evdokimov, and N. A. Ivanova. (Surfactant Properties of Some Reagents Used for Treatment of Drilling Solutions.) Tr., Zapadno-Sib. Nauchno-Issled. Geologorazved. Neft. Inst., v. 103, 1975, pp. 23-27; Chem. Abstr., v. 88, 1978, No. 107605v.

Larsen-Basse, J. Influence of Atmospheric Humidity on Abrasive Wear-I.3 Body Abrasion. Wear, v. 31, 1975, pp. 373-379.

_____. Influence of Atmospheric Humidity on Abrasive Wear-II.2 Body Abrasion. Wear, v. 32, 1975, pp. 9-14.

_____. Wear of Hard Metals in Rock Drilling: A Survey of the Literature. Powder Metall., v. 16, No. 31, 1973, pp. 1-32.

Latanision, R. M., and A. R. C. Westwood. Surfaces and Environment-Sensitive Mechanical Behavior. U.S. Off. Nav. Res.

Rep. NONR-4162 (00), NR 036-055, July 1969, 153 pp.

Ledgerwood, L. W., Jr. Efforts To Develop Improved Oilwell Drilling Methods. *J. Pet. Technol.*, v. 219, 1960, pp. 61-74.

Leisek, J. F. Air-Mist and Detergent Key to Drilling Zones of High Water Volume and Lost Circulation. *Q. CO Sch. Mines Quart.*, v. 58, No. 4, Oct. 1963, pp. 203-206.

Leja, J., and J. H. Schulman. Flotation Theory: Molecular Interactions Between Frothers and Collectors at Solid-Liquid-Air Interfaces. *Trans. Soc. Min. Eng. AIME*, v. 199, Feb. 1954, pp. 221-228.

Lerner, B. E. (Conditions for the Effective Treatment of a Drilling Fluid by Anionic Surfactants.) *Neft. i Gazov. Prom.*, v. 20, No. 1, 1972, pp. 25-27; *Chem. Abstr.*, v. 77, 1972, No. 7973t.

Lerner, R. S., and E. G. Kister. (Antiwear Properties of Drilling Fluids and Their Improvement.) *Tr., Vses. Nauchno.-Issled. Inst. Burovoi Tekh.*, v. 27, 1971, pp. 94-112; *Chem. Abstr.*, v. 81, 1974, No. 51920e.

Lin, I. J., and P. Somasundaran. Alterations in Properties of Samples During Their Preparation by Grinding. *Powder Technol.*, v. 6, 1972, pp. 171-179.

Llenado, R. A., and R. A. Jamieson. Surfactants. *Anal. Chem.*, v. 53, No. 5, Apr. 1981, pp. 174R-182R.

Llenado, R. A., and T. A. Neubecker. Surfactants. *Anal. Chem.*, v. 55, No. 5, Apr. 1983, pp. 93R-102R.

Lowrison, G. C. Fundamentals of the Breakdown of Solids. Ch. in *Dispersion of Powders in Liquids*, ed. by G. D. Parfitt. Applied Sciences Publ., 1981, pp. 273-325.

Lummus, J. L. Drilling Optimization. *J. Pet. Technol.*, v. 22, Nov. 1970, pp. 1379-1389.

Lummus, J. L., and B. V. Randall. Development of Drilling Fluid Friction Additives for Project Mohole. *Am. Pet. Corp.*, Rep. F64-P-54, Jan. 13, 1964, 40 pp.; NTIS PB 175028.

_____. Low-Friction Drilling Fluids. U.S. Pat. 3,472,769, Oct. 14, 1969; *Chem. Abstr.*, v. 71, 1969, No. 126926r.

Lundquist, R. G., and C. F. Anderson. Energetics of Percussive Drills--Longitudinal Strain Energy. *BuMines RI 7329*, 1969, 23 pp.

Matasa, C., and N. Fainita. (Process for Obtaining a Surfactant for Conditioning Drilling Fluids.) *Rom. Pat.* 46,653, Mar. 10, 1967; *Chem. Abstr.*, v. 68, 1968, No. 60780t.

Maurer, W. C. Potential Applications of Novel Rock Disintegration Techniques in Mining. Pres. at Joint Annu. Meet. MN Sect., AIME, and Univ. MN Conf., Duluth, MN, Jan. 12-14, 1970, 17 pp.; available upon request from W. H. Engelmann, BuMines, Minneapolis, Mn.

Memming, R., and G. Schwandt. Anodic Dissolution of Silicon in Hydrofluoric Acid Solutions. *Surf. Sci.*, v. 4, Mar.-Apr. 1966, pp. 109-124.

Mills, J. J., and A. R. C. Westwood. Influence of Adsorption Kinetics on Chemomechanically Enhanced Hard Rock Drilling. *J. Mater. Sci.*, v. 15, 1980, pp. 3010-3016.

Morlier, P. How the Behavior of Rock Under Stress Varies With Its Water Content. *Houille Blanche*, v. 25, No. 5, 1970, pp. 471-475.

Myers, H. M., and J. E. Funk. Fluid Dynamics in a Diamond Drill Bit. *Soc. Pet. Eng. AIME preprint SPE-1696*, 1967, 8 pp.; available upon request from W. H. Engelmann, BuMines, Minneapolis, MN.

Ocepek, D. (Mechanical and Mechano-Chemical Reactions in Crushing Processes.) *Rud.-Metal. Zb.*, v. 12, No. 1, 1969, pp. 5-16.

Odenbaugh, M. L., and R. C. Ellman. Leonardite and Other Materials as Drilling-Fluid Dispersants and Viscosity Control Agents. *BuMines RI 7043*, 1967, 22 pp.

Palmer, H. J. Effect of Surfactants on the Wettability of Fluid Interfaces During Phase Transformation. *AIChE J.*, v. 23, No. 6, Nov. 1977, pp. 831-839.

Paone, J., and W. E. Bruce. Drillability Studies. Diamond Drilling. *BuMines RI 6324*, 1963, 32 pp.

Paone, J., and D. Madsen. Drillability Studies. Impregnated Diamond Bits. *BuMines RI 6776*, 1966, 16 pp.

Paone, J., D. Madsen, and W. E. Bruce. Drillability Studies. Laboratory Percussive Drilling. BuMines RI 7300, 1969, 22 pp.

Paone, J., and S. Tandanand. Inelastic Deformation of Rock Under a Hemispherical Drill Bit. BuMines RI 6838, 1966, 26 pp.

Paredes, E., A. Bustamante, and L. Rivas. Influence of Mineral Oils on Polystyrene Fracture. Polym. Eng. and Sci., v. 23, No. 9, June 1983, pp. 498-502.

Payne, R. The Electrical Double Layer in Dimethyl Sulfoxide Solutions. J. Am. Chem. Soc., v. 83, No. 3, Feb. 1, 1967, pp. 489-496.

Phillips, C. J. The Strength and Weakness of Brittle Materials. Am. Sci., v. 53, 1965, pp. 20-51.

Piggott, M. R. The Rebinder Effect. Acta Metall., v. 12, July 1964, pp. 803-805.

Postash, S. A., V. A. Vopiyakov, V. A. Stepanov, and T. S. Apryatkina. (Feasibility of Increasing the Durability of Rolling Cutter Bits.) Vopr. Geol. i Buren. Neft. i Gazov. Skvazhin, No. 1, 1970, pp. 172-185; Chem. Abstr., v. 78, 1973, No. 18485g.

Pulliam, G. R. Precipitation in Microscopic Cracks. J. Am. Ceram. Soc., v. 42, No. 10, Oct. 1959, pp. 477-482.

Rebinder, P. New Physico-Chemical Phenomena in the Deformation and Mechanical Treatment of Solids. Nature (London), v. 159, 1947, pp. 866-867.

Rebinder, P. A., and L. A. Shreiner. (Physicochemical Method for the Acceleration of Drilling by Adding Ore Softeners to Flush Water.) Gorn. Zh., v. 114, Nos. 8-9, pp. 16-22; Chem. Abstr., v. 33, 1939, No. 1411.2.

Richter, J. P. Cutting Oil Performance - A Significant New Machining Test. Pres. at ASLE/ASME Lubr. Conf., Kansas City, MO, Oct. 3-5, 1977. ASLE preprint 77-LC-2C-3, 7 pp.

Riddick, T. M. Zeta Potential: New Tool for Water Treatment. Chem. Eng. (N.Y.), v. 68, June 26, 1961, pp. 121-126; July 10, 1961, pp. 141-146.

Rimkevich, B. B. (Introduction of Hardness Reducers in Mining Operations.) Promst. Stroit. Mater., No. 2, 1941,

pp. 47-71; Chem. Abstr., v. 38, 1944, No. 2141.

Roscoe, R. The Plastic Deformation of Cadmium Single Crystals. Philos. Mag., v. 21, 1936, pp. 399-406.

Savanick, G. A., and D. I. Johnson. Adhesion at Crystalline Interfaces in Rock. BuMines RI 7709, 1972, 16 pp.

Savins, J. G. Reduction of Friction Losses in Aqueous Fluids in Turbulent Flow. U.S. Pat. 3,361,213, Jan. 2, 1968, 9 pp.; Chem. Abstr., v. 70, 1969, No. 13023e.

Schmidt, R. L. Drillability Studies. Percussive Drilling in the Field. BuMines RI 7684, 1972, 31 pp.

Selim, A. A., and W. E. Bruce. Prediction of Penetration Rate for Percussive Drilling. BuMines RI 7396, 1970, 21 pp.

Shermer, H. F., G. F. Rynders, G. W. Cleck, and D. Hubbard. A Typical pH Response of Some Nonsilicate Glasses. J. Res. NBS, v. 52, 1954, pp. 251-258.

Simon, I., and H. O. McMahon. Study of the Structure of Quartz, Cristobalite, and Vitreous Silica by Reflection in Infrared. J. Chem. Phys., v. 21, No. 1, Jan. 1953, pp. 23-30.

Simon, R. Background Data Explained on Battelle Study of Drilling Fluids. Drilling Contractor, v. 10, No. 4, June 1954, pp. 56-57.

Skells, G. W., Jr., and S. C. Cohen. A Drilling Test for the Evaluation of Cutting Fluid Performance. Lubr. Eng., v. 33, No. 8, Aug. 1977, pp. 401-406.

Smith, W. C. Asbestos in Drill Water Helps Out Drilling Costs. World Oil, v. 151, Sept. 1965, pp. 116-118.

Somasundaran, P., and R. D. Kulkarni. A New Streaming Potential Apparatus and Study of Temperature Effects Using It. J. Colloid and Interface Sci., v. 45, No. 3, Dec. 1973, pp. 591-600.

Spink, K. The Nature of the Diamond Drilling Process. Ind. Diamond Rev., v. 32, June 1972, pp. 230-242.

Tabor, D. Moh's Hardness Scale - A Physical Interpretation. Proc. Phys. Soc., London, v. 67, pt. 3, No. 411B, Mar. 1954, pp. 249-257.

Tandanand, S. Principles of Drilling. Sec. in SME Mining Engineering Handbook, ed. by A. B. Cummins and I. A. Given.

Soc. Min. Eng. AIME, 1973, pp. 11-5 to 11-25.

Tandanand, S., and H. F. Unger. Drillability Determination--A Drillability Index for Percussion Drills. BuMines RI 8073, 1975, 20 pp.

Tarasov, L. P., and N. W. Thibault. Determination of Knoop Hardness Numbers Independent of Load. Trans. Am. Soc. Met., v. 38, 1947, pp. 331-348.

Voitsekhovskii, A. P., and G. A. Elizarov. (Effect of Surfactants on the Properties of Drilling Mud and Holding Strengths of a Boring Column During a Drop in Pressure.) Tr., Krasnodar, Fil. Vses. Neftgazov. Nauchno.-Issled. Inst., No. 20, 1970, pp. 61-67; Chem. Abstr., v. 79, 1973, No. 94256u.

Weiss, W. J., and T. O. Walker. Drilling Fluids Containing Phosphate Ester Acids. S. Afr. Pat. 74 02,914, Aug. 7, 1975; Chem. Abstr., v. 84, 1976, No. 124294c.

Westwood, A. R. C. Effects of Adsorption on Hardness and the Mobility of Near-Surface Dislocations in Non-Metals. Res. Inst. Adv. Studies, Baltimore, MD, Tech. Rep. 66-6, Aug. 1966, 29 pp.

Westwood, A. R. C., and D. L. Goldheim. Cleavage Surface Energy of {100} Magnesium Oxide. Res. Inst. Adv. Studies, Baltimore, MD, Tech. Rep. 63-15, July 1963, 18 pp.

Westwood, A. R. C., D. L. Goldheim, and R. G. Lye. Further Observations on Re-binder Effects in MgO. Philos. Mag., v. 17, No. 149, May 1968, pp. 951-959.

Westwood, A. R. C., and F. E. Lockwood. Chemomechanical Effects in Lubrication. Ch. in Microscopic Aspects of Adhesion and Lubrication, ed. by J. M. Georges. Elsevier, 1982, pp. 421-447.

Westwood, A. R. C., and R. G. Lye. Surfaces and Interfaces in Materials Technology. Ch. in Surfaces and Interfaces II. Physical and Mechanical Properties, ed. by J. J. Burke, N. L. Reed, and V. Weiss (Proc. 14th Sagamore Army Mater. Res. Conf., Raquette Lake, NY, Aug. 22-25, 1967). Syracuse Univ. Press, 1968, pp. 3-57.

Westwood, A. R. C., N. H. Macmillan, and R. S. Kalyoncu. Environment-Sensitive Hardness and Machinability of Alumina. J. Am. Ceram. Soc., v. 56, 1973, pp. 258-268.

Westwood, A. R. C., and J. R. Pickens. Fracture--Applying the Breaks. Ch. in Atomistics of Fracture, ed. by R. M. Latanision and J. R. Pickens. Plenum, 1983, pp. 65-91.

Weyl, W. A. Crystal Chemical Considerations of the Surface Chemistry of Silica. Research, Suppl. (London), v. 3, 1950, pp. 230-235.

Whelan, J. A. Laboratory Studies of Variables in Rotary Drilling. BuMines RI 6129, 1962, 35 pp.

White, C. G. A Rock Drillability Index. Q. CO Sch. Mines, v. 64, No. 2, Apr. 1969, pp. 1-92.

Wiederhorn, S. M. Influence of Water Vapor on Crack Propagation in Soda-Lime Glass. J. Am. Ceram. Soc., v. 50, No. 8, Aug. 1967, pp. 407-414.

Wiederhorn, S. M., and D. E. Roberts. Influence of Normal Alcohols on the Abrasive Wear of Glass. Wear, v. 32, 1975, pp. 51-72.

Wiederhorn, S. M., and P. R. Townsend. Crack Healing in Glass. J. Am. Ceram. Soc., v. 53, No. 9, Sept. 1970, pp. 486-489.

Willard, R. J., and K. E. Hjelmstad. Effect of Moisture and Temperature on the Fracture Morphology of Dacite. Int. J. Rock Mech., Min. Soc., and Geomech. Abstr., v. 8, 1971, pp. 529-539.

World Oil. Guidelines for Optimum Diamond Bit Performance. V. 156, Dec. 1970, pp. 75-77.

Yates, D. J. C. The Influence of the Polar Nature of the Adsorbate on Adsorption Expansion. J. Phys. Chem., v. 60, May 1956, pp. 543-549.

Yates, J. L., Jr. Catalysis Insights for New Techniques and Theory. Chem. & Eng. News, v. 52, Aug. 26, 1974, pp. 19-29.

Yu, V. G., N. V. Pertsov, and B. D. Summ. (Rebinder Effect.) Nauka, Moscow,

1966, 128 pp.; Chem. Abstr., v. 67, 1967, No. 93505q.

Zaionts, O. L., V. Ya. Komar, A. I. Pukas, A. N. Yarov, M. Sh. Kendis, K. M. Gilman, and N. A. Zhidovtsev. (Use of a New Lubricating Additive for Drilling Muds During Diamond Drilling of Geological Boreholes.) Razved. Okhr.

Nedr., v. 36, No. 3, 1970, pp. 37-40; Chem. Abstr., v. 73, 1970, No. 17001f.

Zorin, Z. M., V. P. Romanov, and N. V. Churaev. Contact Angles of Surfactant Solution on the Quartz Surface. Colloid and Polym. Sci., v. 257, No. 9, Sept. 1979, pp. 968-972.